AD-A261 691

DTIC
ELECTE
MAR 5 1993
S C D

ARMY RESEARCH LABORATORY

Vulnerability/Lethality Modeling of Armored Combat Vehicles - Status and Recommendations

William E. Baker
Jill H. Smith
Wendy A. Winner

ARL-TR-42 February 1993

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION IS UNLIMITED.

93-04667

93 3 4 039

NOTICES

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
Febuary 1993

3. REPORT TYPE AND DATES COVERED
Final, Jan 91 - Oct 92

4. TITLE AND SUBTITLE
Vulnerability/Lethality Modeling of Armored Combat Vehicles—Status and Recommendations

5. FUNDING NUMBERS
PR: 1L162618AH80

6. AUTHOR(S)
William E. Baker, Jill H. Smith, and Wendy A. Winner

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
U.S. Army Research Laboratory
ATTN: AMSRL-OP-CI-B (Tech Lib)
Aberdeen Proving Ground, MD 21005-5066

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
ARL-TR-42

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*
The Survivability/Lethality Analysis Directorate of the U.S. Army Research Laboratory has a hierarchy of vulnerability/lethality models including a compartment model, point-burst model, and stochastic point-burst model. The compartment model assesses the vulnerability of armored fighting vehicles by empirically-based damage correlation curves to evaluate probabilities of kill (P_ks) and losses of function (LoFs). The point-burst model considers a burst of behind-armor debris whenever perforation by the main penetrator occurs. Vehicle damage from the main penetrator and behind-armor debris is evaluated and combined using subjective damage-assessment lists to assess P_ks and LoFs. The stochastic point-burst generates distributions of P_ks and LoFs to estimate the probability of occurrence of any particular empirical test result.

Recent concepts, such as vulnerability spaces; new methodologies, such as degraded states; and live-fire testing have significant implications for future modeling efforts. For instance, the historically nebulous distinction between P_k and LoF is being addressed. Introductory studies and results using live-fire data suggest promising avenues to develop a more elementary low-level model.

This report compares and contrasts the advantages, disadvantages, and applications of the existing vulnerability/lethality models. Alternative modeling approaches are identified; and the impact of ongoing research is assessed. Long-term recommendations for vulnerability modeling are specified.

14. SUBJECT TERMS
vulnerability, simulation, lethality

15. NUMBER OF PAGES
62

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	UL

INTENTIONALLY LEFT BLANK.

Table of Contents

INTENTIONALLY LEFT BLANK.

List of Figures

INTENTIONALLY LEFT BLANK.

Acknowledgements

The authors recognize Dr. Aivars K. Celmins, Computational Methods Branch of the Advanced Computing and Information Sciences Directorate of the US Army Research Laboratory (ARL), who was involved in this effort at the time of its inception. We also need to thank four individuals from the Ballistic Vulnerability/Lethality Analysis Division of ARL's Survivability/Lethality Analysis Directorate. We thank Ms. Kathleen L. Zimmerman of the Vulnerability Methodology Branch, and Mr. Lawrence D. Losie of the Ground Systems Branch, for reviewing this report and providing constructive criticism. We also thank Ms. Linda L. C. Moss, Vulnerability Methodology Branch, and Mr. Joseph C. Collins, III, Vulnerability Methodology for their comments while reading a symposium version of this paper.

INTENTIONALLY LEFT BLANK.

1. Introduction

Simulation modeling of physical systems has become increasingly complex. As computers were able to perform more calculations in less time, people began to model all types of real–world activity. Entire languages were developed solely for the use of computer simulations. Models that perform a vulnerability assessment of Armored Fighting Vehicles (AFVs) had been in use for over thirty years at the Ballistic Research Laboratory (BRL). These models continue in use at the US Army Research Laboratory (ARL). They have evolved into three distinct types, each somewhat more sophisticated than the previous. However, they share some common traits.

Each model requires, as part of its input, a geometrical description of the AFV being evaluated. This is a series of basic geometric objects which, when properly combined, will produce a computer–generated replica of both the inside and the outside of the AFV. This geometric representation can be sampled to simulate a threat approaching from any azimuth/elevation combination. Once the threat–target orientation is established, a grid may be overlaid; and rays representing shotlines may be traced through each cell of the grid to determine what general areas and which specific components are hit. These results are compared with a database to provide output from the model.

As a minimum, output from each of the models is in the form of Mobility Loss–of–Function (M LoF), Firepower Loss–of–Function (F LoF), and Probability of a Catastrophic Kill (P_k) for the AFV. M LoF represents a percentage loss of mobility for the AFV; an M LoF of 1.0 (complete loss of mobility) defines the AFV as incapable of executing controlled movement within ten minutes after being hit, not repairable by the crew on the battlefield. F LoF represents the percentage loss of firepower for the AFV; an F LoF of 1.0 (complete loss of firepower) defines the AFV as incapable of delivering controlled fire within ten minutes of being hit, not repairable by the crew on the battlefield. P_k represents the probability of a catastrophic kill of the AFV assuming that it has been hit; a catastrophic kill defines the AFV as totally damaged, not economically repairable.

A computer simulation model called the Compartment model was developed in the late 1950s based on testing done earlier in the decade. It was refined by the Canadian Armament Research and Development Establishment (CARDE) tests performed in 1959 [1]. These tests provided a database from which damage correlation curves were derived and incorporated into the model. In 1979 the independent software programs composing the Compartment model were consolidated into the Vulnerability Assessment Methodology Program (VAMP) [2]. This model can assess the vulnerability of AFVs and Armored Personnel Carriers (APCs) to both kinetic–energy (KE) and shaped–charge (SC) munitions. VAMP is a lumped–parameter or compartment–level model; that is, when shotlines are evaluated, it first checks for perforation by the main penetrator; and, if perforation occurs, it uses damage correlation curves to establish a P_k or to estimate the magnitude of M LoF and F LoF for each compartment breached.

The Vulnerability Analysis for Surface Targets (VAST) model [3, 4] originated in the early 1970s and is more complex than VAMP in that it is a point–burst or component–level model. Like VAMP, when shotlines are evaluated, VAST first checks for perforation by the main penetrator. However, unlike VAMP, when there is perforation, VAST establishes a burst of Behind–Armor Debris (BAD) from that point and evaluates the BAD interaction with critical interior components. BAD can be defined as all the energetic material, excluding the main penetrator/jet or its fragments, which form at the point of armor perforation. Thus, VAST requires a more detailed geometric description of the target vehicle.

Both VAMP and VAST are deterministic models; therefore, the LoFs and P_ks generated by these models are the expected values of these distributions. The results of any particular empirical test may or may not match these expected values. The Stochastic Quantitative Assessment of System Hierarchies (SQuASH) model [5] was developed in the late 1980s. It is a component–level model which generates entire distributions of vehicle LoFs and P_ks, thus allowing the analyst to estimate the probability of occurrence of any particular empirical test result.

The Ballistic Vulnerability/Lethality Division (BVLD) has developed more than the three models mentioned in the previous paragraphs. These additional models include ones devoted exclusively to the evaluation of penetration capabilities, spare parts requirements, personnel incapacitation, and aircraft vulnerabilities. However, the lumped–parameter model (VAMP); the expected–value, point–burst model (VAST); and the stochastic, point–burst model (SQuASH) are the three models currently in production use for the evaluation of conventional direct–fire munitions against ground vehicles;[1] and they are the models which will be discussed in some detail in this report. We will compare them, indicating their strengths and weaknesses. In addition, we will discuss past and present investigations designed to improve vulnerability modeling and outline future directions for this crucial field.

It would seem reasonable at this point to emphasize the analogy between vulnerability and lethality. The vulnerability of a weapon system is an assessment of its susceptibility to damage given a specific encounter with a particular threat. By contrast, lethality is an assessment of the damage effectiveness that a weapon system can inflict on a target in a given encounter. Thus, these terms interpret the same process from different points of view (defense versus offense). For the remainder of this report we will use the term vulnerability with the understanding that the term lethality could be used in an analogous manner.

2. Vulnerability Analysis Framework and Methodologies

2.1. Vulnerability Spaces and Mappings

The concept of vulnerability spaces was introduced in the late 1980s [9]. It serves as a framework through which the complex interrelationships present in the area of vulnerability analysis can be more easily understood. **Figure 1** shows the four spaces of vulnerability.

Every point in space 1 represents a threat–target interaction, including the orientation and the hit point of the munition and many other parameters describing the encounter. The number of points in space 1 is infinite.

Space 2 contains the component damage vectors. A component damage vector is a representation of the vehicle after all threat damage has occurred. Assuming the vehicle contains **n** components which are critical to the completion of its mission, the component damage vector is, in fact, merely an **n**–tuple, each element of which is either a 0 or 1 indicating the state of the component as either functional or nonfunctional. If the vehicle has **n** critical components, then the maximum number of possible damage states is 2^n. Thus, the number of points in space 2 is large, but finite. Associated with each **n**–tuple in space 2 is a list of post–shot observables such as entrance holes and exit holes in armor packages and components caused by the primary threat and spall distribution. Due to the inherent variability of these observables, it is expected that if an experiment from space 1 was repeated many times, each replication could conceivably map into a different point in space 2.

Space 3 represents objective measures of performance (MOPs), which are measures of the reduction in vehicle performance resulting from mapping component damage state(s). For example, an MOP may be a reduction in rate of fire (caused from damage to the autoloader) or a reduction in forward mobility (due to the loss of the reverse gear in the transmission). Many points in space 2 may map into the same point in space 3. The Degraded

[1]The Modular UNIX®–based Vulnerability Estimation Suite (MUVES) [6–8] is the new computing environment for the conduct of vulnerability/lethality (V/L) studies within the BVLD. MUVES employs the latest software technologies both in design and implementation to leverage scarce V/L analyst resources, improve the ability to incorporate methodology advances, provide an audit trail of the analyses, and facilitate configuration management and archiving of analyses. MUVES is a suite of packages that are ANSI C compliant and run on System V® compatible UNIX® platforms. MUVES provides a user–friendly, menu–driven interface for the conduct of V/L analyses. Currently, the compartment–level model, VAMP, is implemented under this environment, and the stochastic point–burst model, SQuASH, is in the process of being implemented under this environment. ®UNIX and System V are trademarks of AT&T.

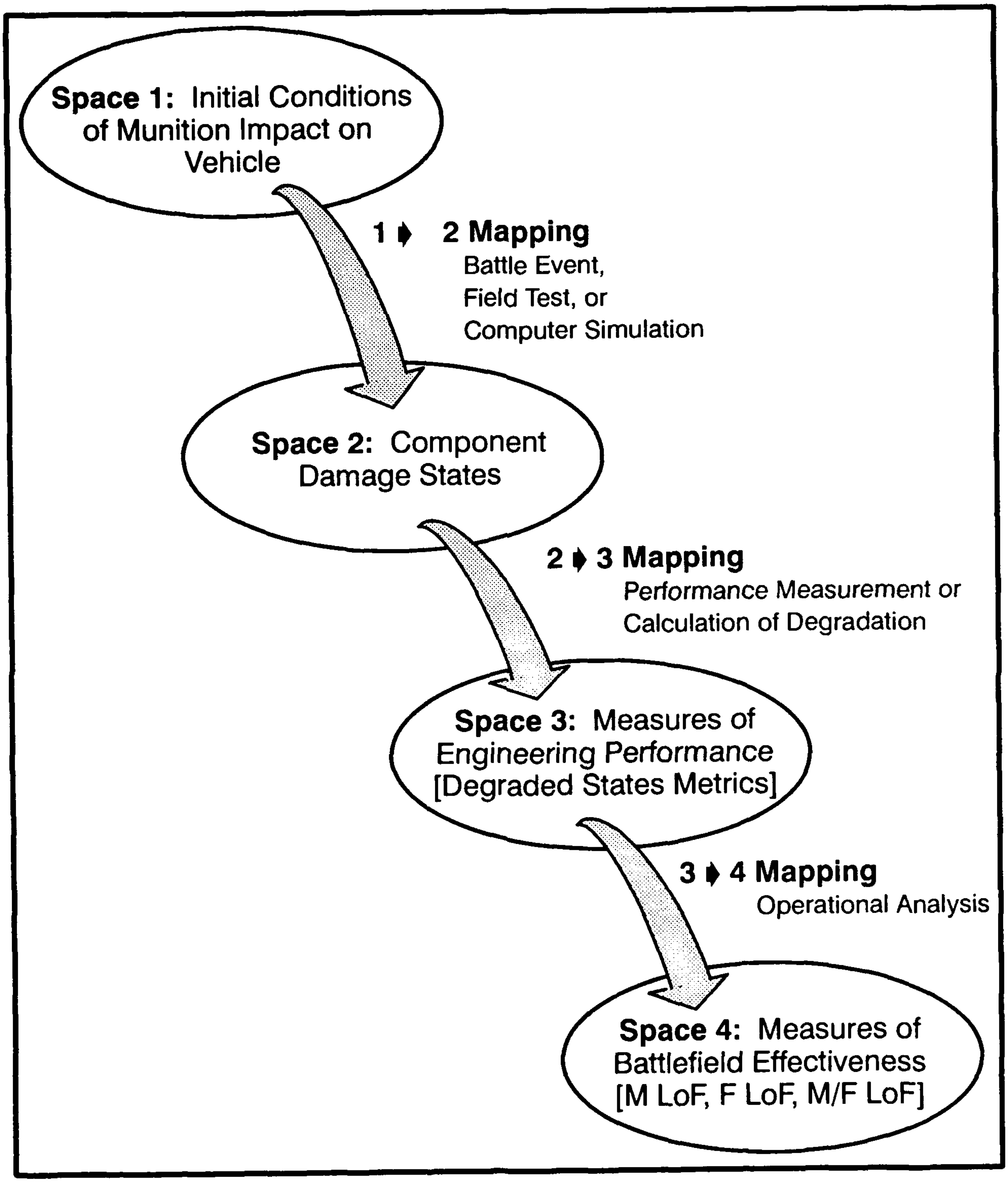

Figure 1. Spaces of Vulnerability Analysis.

States (DS) methodology [10–12] defines a mapping from space 2 to probability subspaces of space 3.[2] This methodology is discussed in Section 2.2.

Finally, space 4 is the Measures of Effectiveness (MOEs) space. Historically, this domain was defined as a probability space. It is actually composed of several subspaces, most of which are not probability spaces. For example, catastrophic kill (*i.e.*, P_k) is a probability subspace of space 4, while M LoF and F LoF are non–probability subspaces [9, 13]. The traditional Damage Assessment List (DAL) methodology defines a mapping which completely bypasses space 3; each point in space 2 maps into one point in each of the subspaces of space 4.

2.2. Methodologies Utilized in V/L Codes

Vulnerability/lethality codes for AFVs implement numerous algorithms. These algorithms often are a result of analyses of experimental data and simulation codes performed by experts working in related but specialized fields. Some algorithms and methodologies have become associated with a particular V/L code since they are only used in one code; however, in other cases, a methodology is used in all AFV vulnerability codes. V/L codes for AFVs typically use algorithms for penetration, component probabilities of kill given a hit ($P_{k|h}$s), and BAD.

Penetration models include algorithms, such as the Fireman–Pugh and DiPersio, Simon, Merendino (DSM) algorithms for modeling SC jets [15–17]; various models for explosively formed penetrators; Grabarek's penetration equations [19]; Segletes' method for top–attack/canted warheads [20]; or Frank's models for penetrating modern armors [21]. In compartment–level models, the line–of–sight subtraction method [8,18] is applied to tabulated data which has been computed from KE penetration algorithms such as Grabarek's and Frank's. Component $P_{k|h}$ and BAD methodologies include the lethal spall fragment algorithms [22], COMPKILL algorithms [23], and Direct Lethality (DL) methodologies [24].

Definitions of MOEs and MOPs, and the methods for computing these quantities have also been independently derived methodologies. These have such a profound effect on V/L computations and simulation codes that they are summarized in the remainder of this section.

LoF values, such as M LoF and F LoF, whether used in the compartment–level model or the component–level models, represent a percentage of degradation for a particular function of the AFV, an expected utility. In component–level codes, these values are computed by a DAL derived by a panel of convened experts. DALs are based on the notions of a vehicle's combat utility and the degradation in its combat utility from killing a component or a set of components integrated over "all" combat missions/scenarios. Thus, a DAL is a mapping between components/systems and a degradation in combat utility. Rigorous and consistent definitions for these terms do not exist [10, 14].

When examining an F LoF value of 0.5, it is understood that the firepower function of the vehicle is degraded to 50 percent of full firepower. This itself is vague in that it is unclear whether the rate of fire of the main armament is cut in half, the fire control unit has lost 50 percent of its efficiency, the secondary armament is totally destroyed, or any one of several other possible interpretations of the phrase. Compounding this problem is the fact that LoF values are computed using the Laws of Probability, although there is no justification for this action. The probability of a complete loss of a measure of effectiveness (*e.g.*, firepower) is certainly different from the expected loss of this measure, and yet these terms have been used interchangeably [10, 14].

The Degraded States methodology [10–12] overcomes the conceptual and mathematical problems intrinsic to DALs and LoFs. For the most part, this work has been developed by Dr. Michael Starks, Ms. Lisa Roach, and Mr. John Abell of the BVLD based on earlier work by Mr. James Rapp. The outputs of this methodology are

[2]At least one prior report [13] inadvertently specified DS methodology as a mapping from space 2 to 4 and specified degraded states as a Space 4 metric.

MOP metrics. This methodology maps the damage to individual components to quantifiable vehicle damage states (which themselves define a loss of engineering performance) and the probabilities of achieving these states.

Degraded states are a set of metrics which define a vehicle's performance degradation in terms of mission–related subsystems (typically mobility, firepower, acquisition, crew, communications, and ammunition) that support the various functions of the vehicle (mobility, firepower, and so forth). Each mission–related subsystem is defined by a number of mutually exclusive and exhaustive degraded states which describe the functional performance capabilities of the vehicle. For instance, an acquisition subsystem may be defined in terms of four degraded states: no acquisition damage, reduced acquisition capability, inability to acquire while moving, and reduced acquisition capability with an inability to acquire while moving. Such degraded states detach the vehicle's performance from its mission in a particular battlefield situation. It should be noted that degraded states may not be independent for the different vehicle functions. BVLD personnel are working on establishing the proper method of handling such damage states.

Each degraded state is defined in terms of mathematical fault trees. A fault tree specifies the parallel and serial relationship of components, which if lost, would result in such a degraded state. For example, reduced acquisition capability for the acquisition subsystem of a particular vehicle might include crew vision blocks, weapon sights, cables, and electric power. For the most part, such information is available from criticality analysis of the AFV. Thus, expert knowledge about the operation of the vehicle is entered into the vulnerability analysis in the form of fault trees and component $P_{k|h}$s. This can be a sizeable effort for one AFV.

An advantage of degraded states over LoFs is that logically sound and mathematically rigorous estimates for probability for each degraded state can be estimated. In some cases, it may be possible to compute estimates by repeatedly sampling events using validated model algorithms and inputs for similar components/systems. In other cases, estimates may be obtained from test firings. Validation of the degraded states fault trees, which map component damage to degradation in performance, may be possible for some systems using data obtained via non–destructive testing. For example, a roadwheel could be removed and the degraded mobility state could be assessed.

The advantages of the DS methodology and degraded states probability measures include those mentioned by Rapp [14] along with others [11] and can be summarized as follows:

- logically sound and mathematically rigorous
- readily understandable metrics which are not prone to misinterpretation
- underlying fault trees are unambiguous and can be constructed without extrapolating from previous analyses
- meaningful and useful subsystem evaluations
- capable of providing a quantitative basis for comparing systems' vulnerabilities
- amenable to computation in V/L component codes
- able to validate with non–destructive as well as destructive testing
- amenable metrics for war game simulation codes [25]

3. Current Models

3.1. Lumped–Parameter Model

A lumped–parameter model, also called a compartment–level model [8], is a simulation code in which the geometric representation of the target description is at a compartment level; major systems of components are grouped both functionally and physically, and are modeled as one entity (*i.e.*, compartment). All LoFs are related to main–penetrator residuals by "lumped–parameter" relations. LoF is evaluated for each affected compartment and then combined with the LoF of other compartments to compute the overall vehicle LoF.

Figure 2 [26] shows the three–dimensional (3–D) geometric representation of a Future Infantry Fighting Vehicle (FIFV) used for compartment–level analyses. The compartments that are evaluated for contribution to the degradation in vehicle performance are the crew compartment shown as individual crew members, the passenger compartment shown as individual passengers, the engine compartment in the forward hull, the ammunition compartments shown in the bustle, the fuel shown in the rear hull, and various components of the suspension system such as track, idler wheel, first road wheel, sprocket hub, *etc.* that are modeled individually. Each of these compartments/suspension components has associated damage correlation curves that relate potential degradation in functionality of the vehicle to M LoF, F LoF, and P_k. For instance, LoF/P_k for a particular compartment/suspension component may be looked up based on the KE penetrator diameter, the KE projectile diameter, the warhead charge diameter, the profile hole diameter through the armor, or the residual penetration. LoF/P_k of more than one compartment caused by penetrating more than one compartment is combined using the survivor rule[3] to give the overall vehicle LoF/P_k for the given shotline.

In referring to the spaces of vulnerability, the compartment model maps from the initial conditions of space 1 (*e.g.*, penetrator diameter, warhead cone diameter) and from intermediate measures of damage derived from space 1 (*e.g.*, profile hole diameter, residual penetration, *etc.*) to the MOEs of space 4 (**Figure 3**).

For a typical vulnerability run using the compartment–level model, each 4in or 100mm square grid on the target is sampled via ray–tracing. Penetration of the target geometry is computed using the appropriate penetration algorithms for KE penetrators and SC jets. Performance is degraded as the penetrator/jet moves through the target. Since exterior armor is modeled, the ability to perforate armor into the internal volume of the vehicle is one output available from the compartment model. In addition, the residual penetration capability can also be produced. The compartment model penetration algorithms are the same as the penetration algorithms for our other models. Hence, the compartment model does as well as the other models in investigating armor protection trade–offs.

The compartment model, however, is not the model of choice for component trade–off studies/comparisons. The damage correlation curves in the compartment model are, to a large extent, based on technology from the 1950s when data were collected to develop the curves. The modeling of the compartments and interrogation via ray–tracing allow only for the comparison of size and placement of the collection of components that make up the compartments and does not provide any comparison of differences due to individual changes in component technology. There is no rationale for changing these curves to reflect recent technology advances. Given the advancement of vulnerability modeling, conducting a series of tests necessary to update these curves would not be the best use of our resources. In such a complex set of interactions, the correlation of LoF/$P_{k|h}$ with one variable for each compartment/component has large inherent variations that cannot be accounted for and would lead to very wide confidence bounds for the model. Investigations in this area will be addressed in Section 4.1.

Figure 4 summarizes compartment model applications, required inputs, applied methodologies and model outputs as well as the advantages and disadvantages of the compartment model as implemented under the MUVES environment.

[3] The survivor rule used in VAMP assumes independence and states that vehicle LoF is computed for n critical components by combining the LoF of each component as follows:

$$LoF = 1 - [(1 - LoF_1)(1 - LoF_2)\ldots(1 - LoF_n)].$$

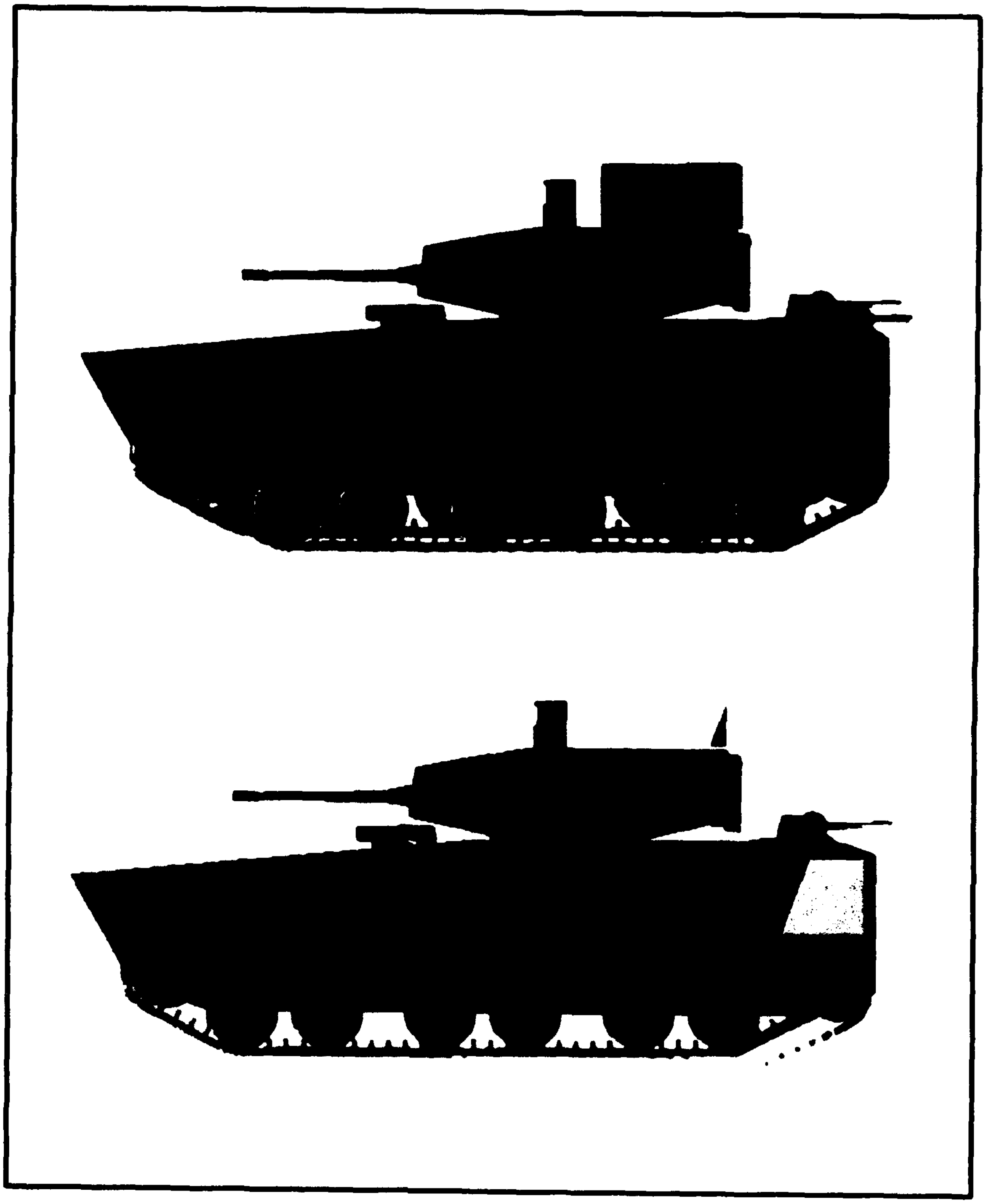

Figure 2. Compartment-level representation of a Future Infantry Fighting Vehicle.

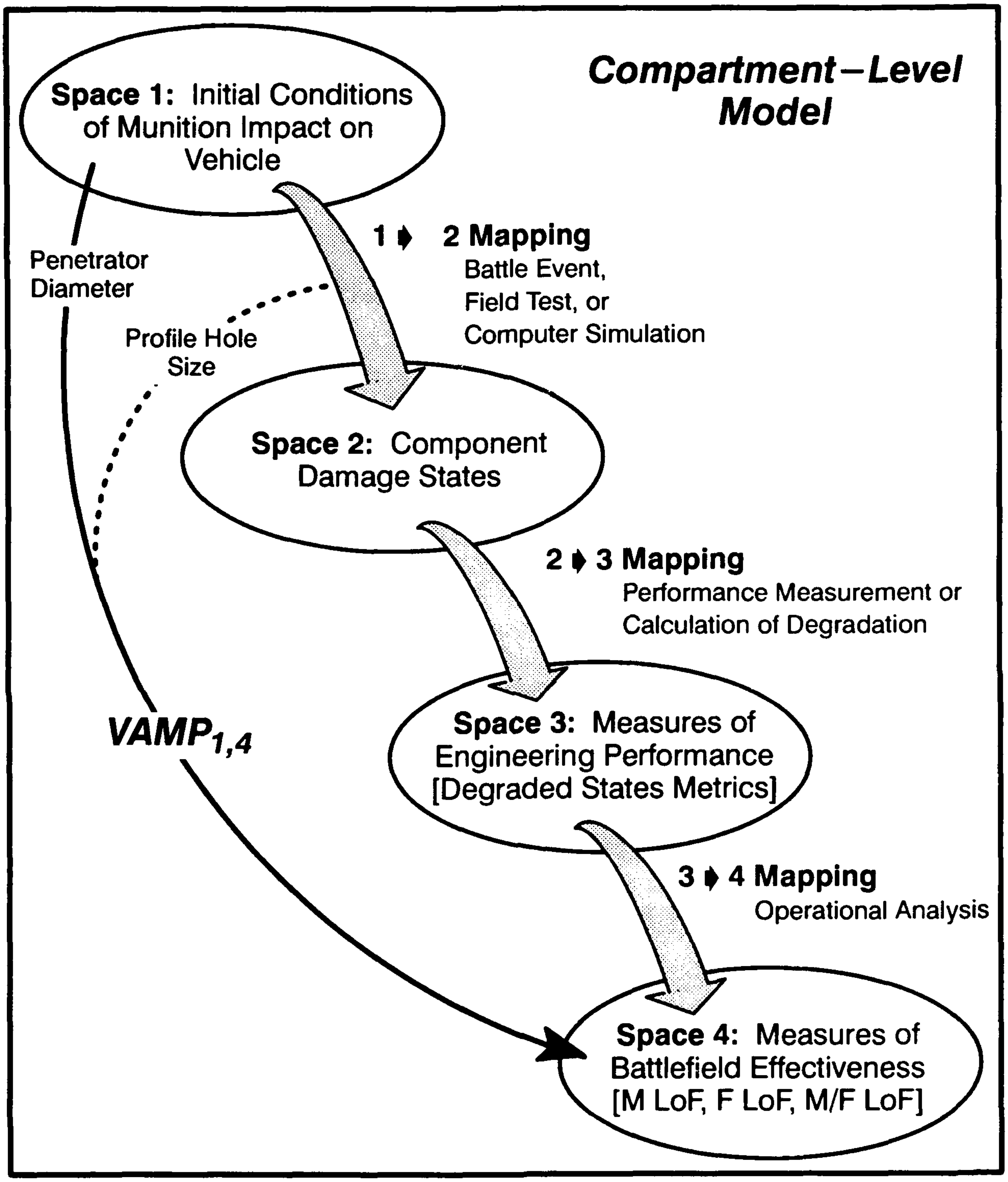

Figure 3. Spaces of Vulnerability Analysis— —Compartment–Level Model.

Model Applications

- Cost and Operational Effectiveness Analyses (COEAs).
- Mission Area Analyses (MAAs).
- Concept vehicle studies and other studies where vehicle component detail is unavailable.
- Primary model for inputs to war games.

Model Inputs

- Simple 3-D solid geometric model of the AFV.
- AFV-specific armor and component/compartment properties.
- Threat performance and capabilities.
- Threat impact location(s) on the AFV via shot or shot grid specifications.
- Damage correlation curves for compartments/suspension/personnel.

Methodologies Applied

- Geometric ray-tracing techniques.
- Penetration algorithms:
  - For KE munitions: Grabarek, other specialized algorithms.
  - For SC rounds: Fireman-Pugh, DSM.
- Lethal spall fragments for crew compartment (SC) and passenger compartment (SC & KE).
- Damage correlation curves for ammunition compartment, engine compartment, crew compartment, passenger compartment, fuel, gun tube, track, track edge, track face, idler hub, idler, sprocket hub, sprocket, first roadwheel hub, first roadwheel, last roadwheel hub, and last roadwheel based on damage correlation curve look-ups.

Model Outputs

- Exterior armor perforation.
- Residual penetration capabilities.
- Expected M LoF, F LoF, M/F LoFs, and P_ks for each shotline.
- Combat-weighted averages of LoFs and P_ks using view, aim dispersion, target exposure, weapon bias, and range.
- Graphical plots and tabular summaries of LoFs/P_ks by cell and shotline.

Figure 4. Summary of the MUVES Implementation of the Compartment Model.

Advantages

- Exterior armor perforation computations based on same algorithms as point–burst and stochastic point–burst codes.
- Minimal input requirements including geometry as compared with higher resolution models.
- Includes all damage mechanisms implicitly in the damage correlation curves.
- Shortest analysis run times as compared with higher resolution models.
- Incorporated under the MUVES environment.

Disadvantages

- No direct code linkage to other V/L models outside of the MUVES environment.
- Lumped–parameter approach to physical interactions.
- Produces no field observable values for model validation with test data.
- Deterministic point estimates without variability estimates have limited utility in determining true differences among AFVs.
- Large variability in data used to generate damage correlation curves propagates errors throughout the methodology.
- Damage correlation curve inputs based on older AFV technologies.
- Limited ability to incorporate new technological improvements (such as new munitions, new component technologies, and novel vulnerability reduction measures).
- Cannot separate damage produced by the different damage mechanisms.
- Inputs must be extrapolated for untested munitions and/or AFVs.

Figure 4. Summary of the MUVES Implementation of the Compartment Model.
(Continued)

3.2. Expected–Value Point–Burst Model

Internal point–burst vulnerability models, also called component–level models, represent a greater level of complexity than compartment–level models in that they consider the detailed interior of the AFV. These models concentrate on damage from the main KE penetrator or SC jet along with damage from the accompanying fragments which are formed when the main armor is perforated. They explicitly evaluate the damage to interior components resulting from the fragment cloud of behind–armor debris. This cloud is depicted as a conical bundle of rays "bursting" from a single "point" of perforation; hence, the name point–burst model. With the exception of the suspension system for which blast effects are considered, these models ignore secondary damage mechanisms such as blast, ricochet, shock, toxic fumes, and fires. Such mechanisms, however, are implicitly included in the damage correlation curves embedded in the compartment–level model.

The VAST model originated in the early 1970s to evaluate the vulnerability of APCs and AFVs to KE penetrators and SC warheads. It was written by Mr. David Priest of Watervliet Arsenal and documented by Mr. C. L. Nail through a contract between BRL and Computer Sciences Corporation [3, 4]. VAST was based on the Spall Handling Universal Threat Evaluation (SHUTE) program developed by Mr. Tom Hafer of the BRL [27], which was itself based on an earlier "parallel–ray" vulnerability analysis program. Like the compartment–level model, VAST's deterministic output consists of first–order estimates for the probability of catastrophic kill and the loss of functions, both mobility and firepower. However, it is a point–burst model and includes submodels of BAD data which describe the vulnerability of interior critical components struck by fragments.

For any given shot, VAST estimates the probability of killing each critical interior component of the vehicle given a hit on that component ($P_{k|h}$). This conditional kill probability depends on the type of munition (KE or SC). It is also a function of parameters related to the mass, velocity, and shape of BAD fragments, as well as the characteristics of the component itself. Mass and velocity of fragments are determined by the penetration equations derived from the THOR project [28, 29].

To compute LoFs, fault trees are established which combine vehicle components in series and parallel to reflect the designs of the major subsystems of the AFV. The vulnerability of these subsystems is obtained by combining the individual component kills using the laws of probability. The DAL provides a function which maps the individual damaged component/subsystem into an expected degradation of combat utility of the AFV. Overall target vulnerability is then computed by applying the survivor rule to the subsystems' results, *i.e.*, the subsystems are assumed to be independent. However, this mapping defined by the DAL takes into consideration a number of different scenarios, doctrines, *etc.* and, hence, has the tendency to average out the very features that the combat–level simulations are examining.

For the main penetrator, the conditional probabilities of kill for individual components are derived using the theories of DiPersio, Simon, and Merendino [16] (for SC jets) and the THOR equations (for KE penetrators). Fragment lethality is computed using the BAD data along with estimates of component $P_{k|h}$ for single–fragment impacts, which are input to VAST.

Figure 5 shows how VAST relates to the spaces of vulnerability analysis. Being a component–level model, VAST is much more complex than the compartment–level model. It requires detailed interior geometry which contains all of the components critical to the various functions of the AFV. For example, **Figure 6** depicts a component–level description of the Bradley Fighting Vehicle. VAST is sensitive to the placement of the interior components and to the role each component contributes to various vehicle functions. It also requires a detailed knowledge of BAD data for every combination of munition and armor to be evaluated along with $P_{k|h}$ data for all critical components. However, given this information, system predictions are available without the full–scale experiments necessary to develop the damage correlation curves used in the compartment–level model.

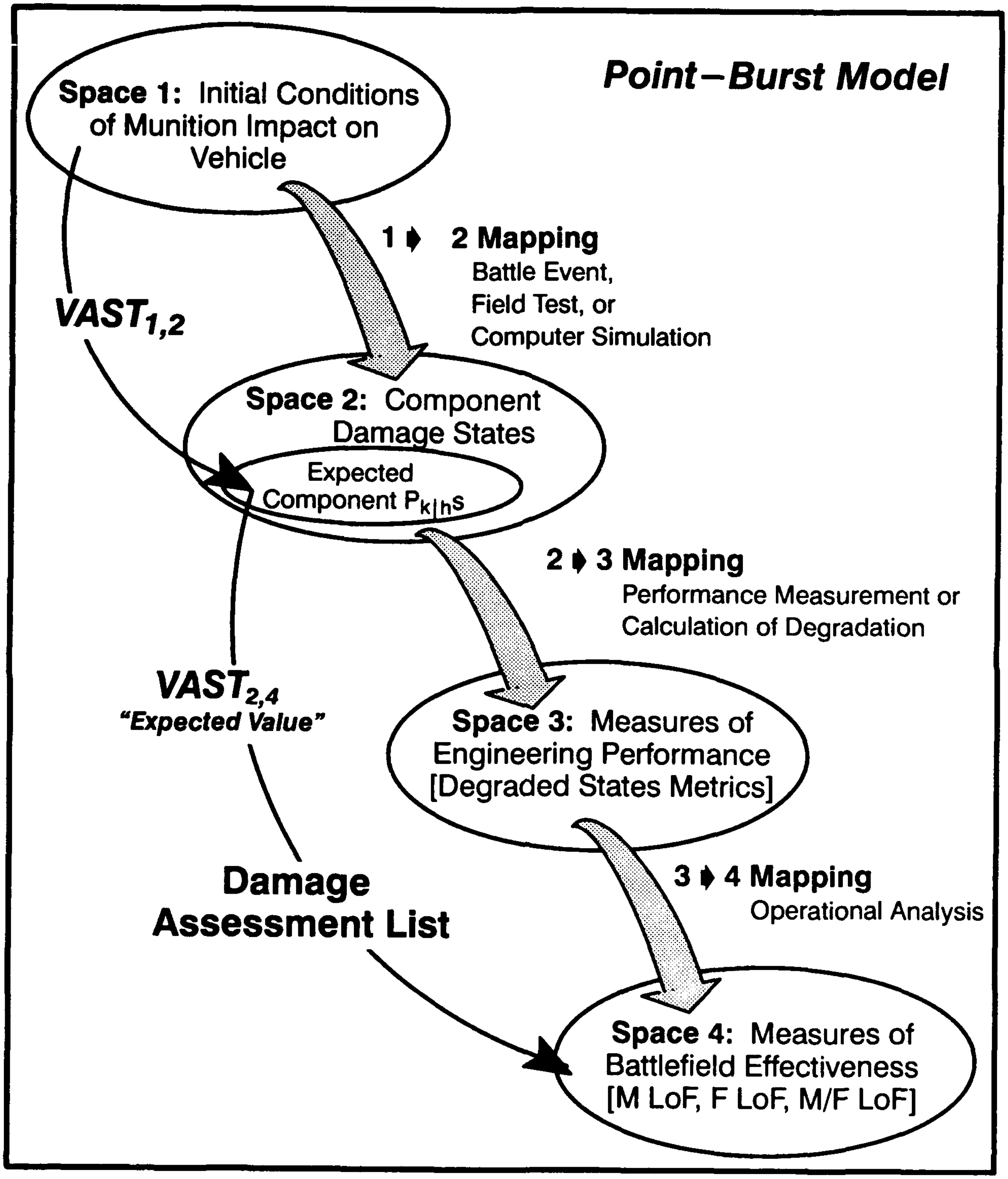

Figure 5. Spaces of Vulnerability Analysis– –Point–Burst Model.

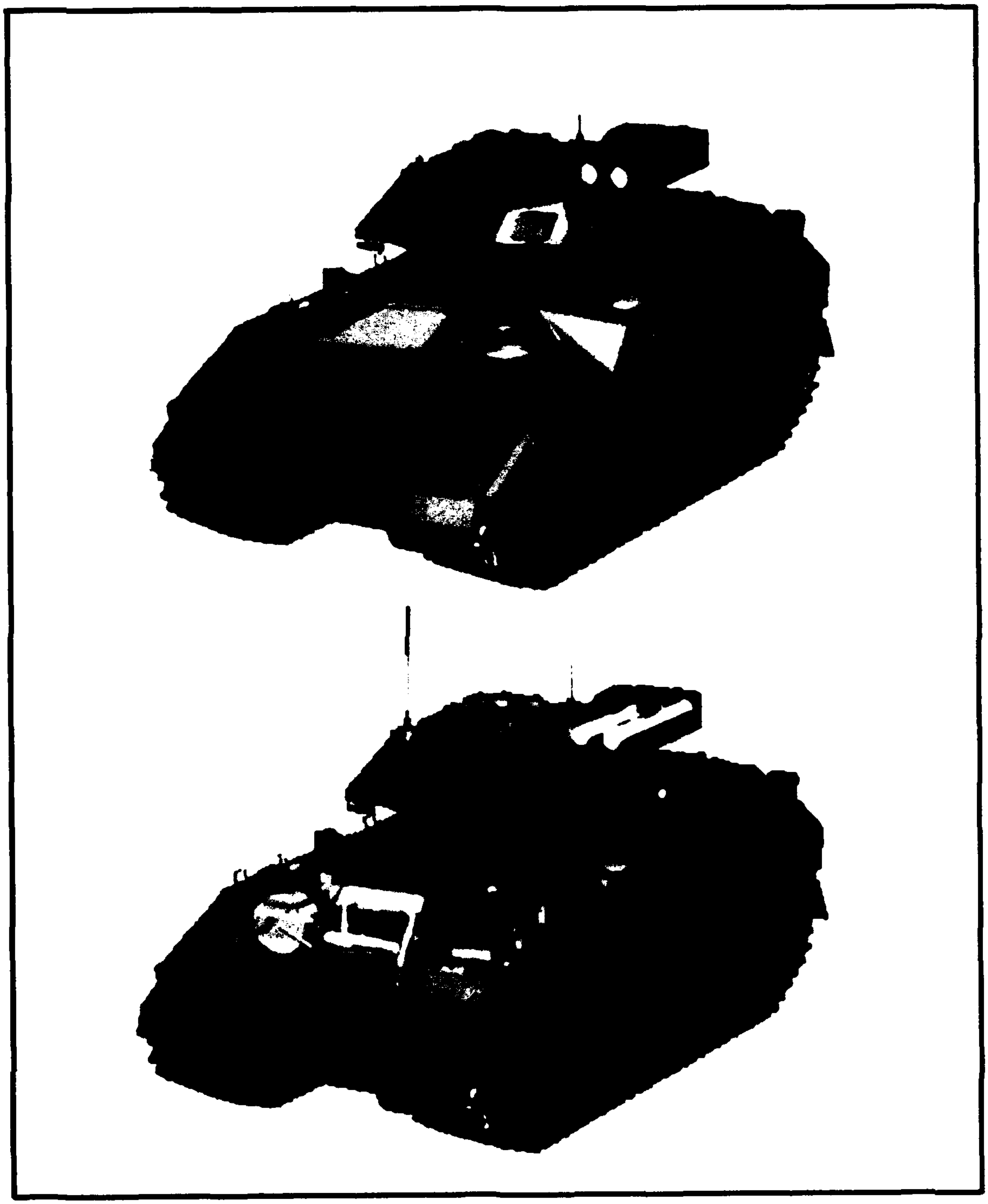

Figure 6. Exterior and Transparent Armor Views of the Bradley Fighting Vehicle.

Of course, each damage source in VAST must be explicitly modeled, whereas factors such as shock and blast are implicitly included in VAMP's damage correlation curves.

In spite of the increase in detail over the compartment–level model, VAST still presents some problems for the vulnerability analyst. The largest of these is the fact that it is a deterministic model, and, as such, it purports to compute the expected values, E[x], of the distributions of the LoFs and P_k of the vehicle. It is incapable of computing the *probability* of encountering a single particular damage state. Thus, the model has virtually no capability of predicting the results of an individual field experiment. Also, the vulnerability estimates are obtained by combining the results of experiments involving threat/armor pairings as well as experiments concerning the susceptibility of individual components to fragment damage. The BAD and component $P_{k|h}$ data from these experiments are required as input to the model, but often such data are unavailable or insufficient. Finally, both the probability procedures and the survivor rule assume independent events; and since this is generally not true, biased estimates of the vehicle's vulnerabilities are computed.

A fundamental assumption of any deterministic expected–value model is that the processes dependent on random variables can be adequately simulated by replacing such variables with a measure of the central tendency of their underlying distributions during some phase of the modeling process. Thus, such a model uses the expected values of the distributions of the input variables, combining them in a deterministic manner. However, in general, a function of an expected value is not equal to the expected value of the function, *i.e.*, $f(E[x]) \neq E[f(x)]$. Furthermore, a loss of information is incurred when the distribution of a random variable is suppressed, *e.g.*, the range of possible outcomes is lost. These limitations were evident in the VAST analyses in support of the Bradley Live–Fire Test (LFT) Program. However, VAST was the only V/L model available for analyses in support of this initial LFT program in 1988. Observed limitations included: (1) Damage state information could not be predicted; (2) VAST did not have algorithms for certain small components (*e.g.*, electric wires, hydraulic lines, fuel lines and fuel filters) which impacted post–shot performance; (3) VAST lacked random variability; (4) Expected kill values were predicted for which there was no supporting test data; and (5) Expected kill values were not comparable to LFT observables.

The compartment–level model remains the production model when performing studies of targets and/or munitions for which detailed information is not available. However, VAST has been used to evaluate the Bradley Fighting Vehicle, one AFV for which no damage correlation curves are currently available. It is also used to compute vulnerable areas of targets for indirect–fire munitions and to determine spare parts needs.

Finally, one additional problem with VAST arises from the number of different versions of the model which currently exist. Each of these contains algorithms tailored at one time to a specific target or a specific study. Although there is no single VAST model, **Figure 7** summarizes the prevalent characteristics of its several versions.

Model Applications

- Lethality enhancement/vulnerability reduction.
- Component level studies.
- Vulnerable areas for indirect–fire munitions.
- Spare parts requirements for repair of battle damage.
- Inputs to war games for indirect–fire munitions.

Model Inputs

- Detailed 3–D solid geometric model of the AFV.
- AFV–specific armor properties.
- AFV–specific critical component $P_{k|h}$s.
- Criticality analysis for detailed AFV geometric description.
- Threat performance and capabilities.
- Threat impact location(s) on the AFV.
- DAL for detailed AFV geometric description.
- BAD data.

Methodologies Applied

- Geometric ray–tracing techniques.
- Penetration algorithms:
  - For KE munitions: THOR, Grabarek, other specialized algorithms.
  - For SC rounds: Fireman–Pugh, DSM.
- BAD and critical component $P_{k|h}$s.
- Kokinakis–Sperrazza personnel incapacitation.
- DAL.

Model Outputs

- Exterior armor perforation.
- Expected M LoF, F LoF, M/F LoFs, and P_ks for each shotline.
- Expected critical component kill probabilities.
- Combat–weighted averages of LoFs/P_ks using view, aim dispersion, target exposure, weapon bias, and range.
- Graphical plots and tabular summaries of LoFs/P_ks by cell and shotline.

Figure 7. Summary of VAST's Salient Characteristics.

Advantages

- Does not require correlation curves based on full-scale experiments.
- Handles indirect-fire munitions.
- Able to investigate component trade-offs.
- Can provide inputs for spare parts analyses.
- Explicitly models blast effects of SC jets on suspension components.

Disadvantages

- No direct code linkage to other V/L models.
- Input requirements exceed the requirements of the compartment model.
- Space 4 results based on a DAL mapping which "averages" over scenarios, doctrines, *etc*.
- Expected values suppress information about distributions of possible outcomes.
- Expected-value point estimates without variability estimates have limited utility in determining true differences among AFVs.
- Outputs only expected values which cannot be compared with field observations for validation purposes.
- Does not model ricochet, shock, toxic fumes, fires or spall effects from secondary/tertiary sources.
- Fault tree analysis assumes independent probability values.
- BAD data required for every target/threat combination.
- May suffer from extreme sensitivity to insignificant changes of BAD data.
- Different versions of code exist, resulting from algorithms individually tailored to specific AFVs.

Figure 7. Summary of VAST's Salient Characteristics.
(Continued)

3.3. Stochastic Point–Burst Model

The vulnerability assessment code named the Stochastic Quantitative Analysis of System Hierarchies (SQuASH) was initiated in the late 1980s to overcome the limitations of expected value V/L models [5]. SQuASH is BVLD's only stochastic point–burst code. It is currently the Army's model of choice for Live–Fire Test and Evaluation (LFT&E) of AFVs. SQuASH has also been used to estimate spare parts requirements. More importantly, SQuASH has been used to explore methods for improving the compartment model or developing a new low–level V/L model (as discussed in Section 4).[4]

The stochastic point–burst methodology [5, 9] improves on the point–burst methodology by using repeated sampling of random variables to provide highly detailed predictions. A distribution of damage vectors (where each vector describes the functional/non–functional state of every critical vehicle component) is computed by repeatedly simulating the threat impact. This is a significant improvement over the point–burst methodology. Component damage vectors are the only measure for analytically verifying agreement between a model and a physical event. Estimates for the probability of occurrence of a particular target–threat interaction (space 2 outcome) can be computed from the predicted distribution of damage vectors. The stochastic point–burst methodology also computes the vehicle LoFs and P_k distributions. By more recently linking the independently developed DS methodology [11, 12] into the stochastic point–burst code, this code has the ability to measure performance degradation in terms of mission–related kill categories. Thus, in the spaces framework, a stochastic point–burst code can perform the space 1 to 2 mapping, the space 2 to 3 mapping (using DS methodology), and the space 2 to 4 mapping (using DAL methodology) (**Figure 8**).

Compared to the compartment code, inputs to the stochastic point–burst code are numerous. Inputs include a detailed 3–D geometric characterization of the AFV (*e.g.*, components, spatial location of components, component properties, *etc.*) (**Figure 9**), threat information (*e.g.* shaped–charge warhead/jet performance, residual penetration capabilities), the threat's impact location(s) (either a specific location or a set of Monte Carlo impact locations for a full view), spall inputs (*e.g.*, the expected number of lethal fragments), the critical component probabilities of a kill given a hit, deactivation diagrams, and a DAL or DS fault trees.

Analogous to VAST, all critical components as well as non–critical components capable of producing spall must be geometrically modeled to accurately predict Live–Fire Test (LFT) observables. Deactivation diagrams from the criticality analysis must also be specified. Analogous to VAST, the criticality analyses must include deactivation diagrams for all critical components in the fuel supply system, fuel control system, fuel, engine power transfer system, engine power, electrical system, hydraulic system, suspension, NBC system, driver's controls, traversing system, gun elevation system, armament, and communications system. Such diagrams exclude armor and fire suppression system(s) as well as crew members and passengers. Loss or damage to the armor and fire suppression system(s) are not included in the criticality analysis since they do not directly contribute to M LoF, F LoF, or P_k. Incapacitation to crew and passengers is modeled using a SQuASH–improved Kokinakis–Sperrazza algorithm [30]. In the case of SQuASH code using the DS methodology, a set of DS fault trees are used to define critical components and their relationship to each of the mission–related kill categories.

The principle difference of SQuASH's internal computations from VAMP and VAST is that Monte Carlo simulations are performed for each target–threat interaction (*i.e.*, shot). Monte Carlo sampling is used for the following random variables: (1) the threat's impact location on the AFV, (2) the penetration capability of a KE munition on initial AFV impacts, (3) the residual KE penetration ability, (4) the initial penetration depth of a SC jet, (5) the spatial characterization of spall, (6) the number of lethal spall fragments, (7) a kill/no–kill assessment of a critical component from the effects of the main KE penetrator, KE penetrator fragment(s), or a SC jet,

[4] The MUVES–implementation of SQuASH is expected to be available for pre–production testing in FY93 and will facilitate these preliminary studies.

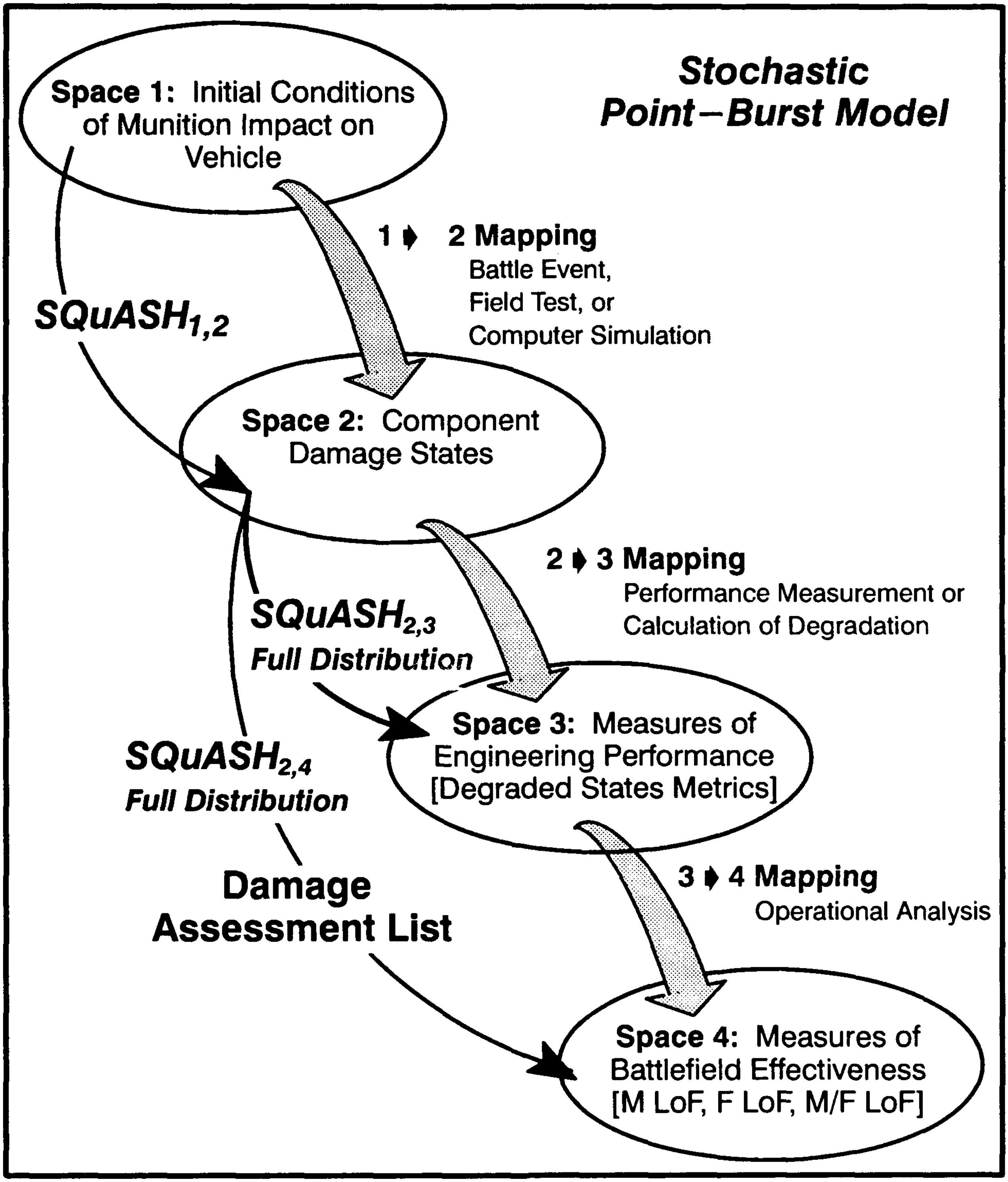

Figure 8. Spaces of Vulnerability Analysis— –Stochastic Point–Burst Model.

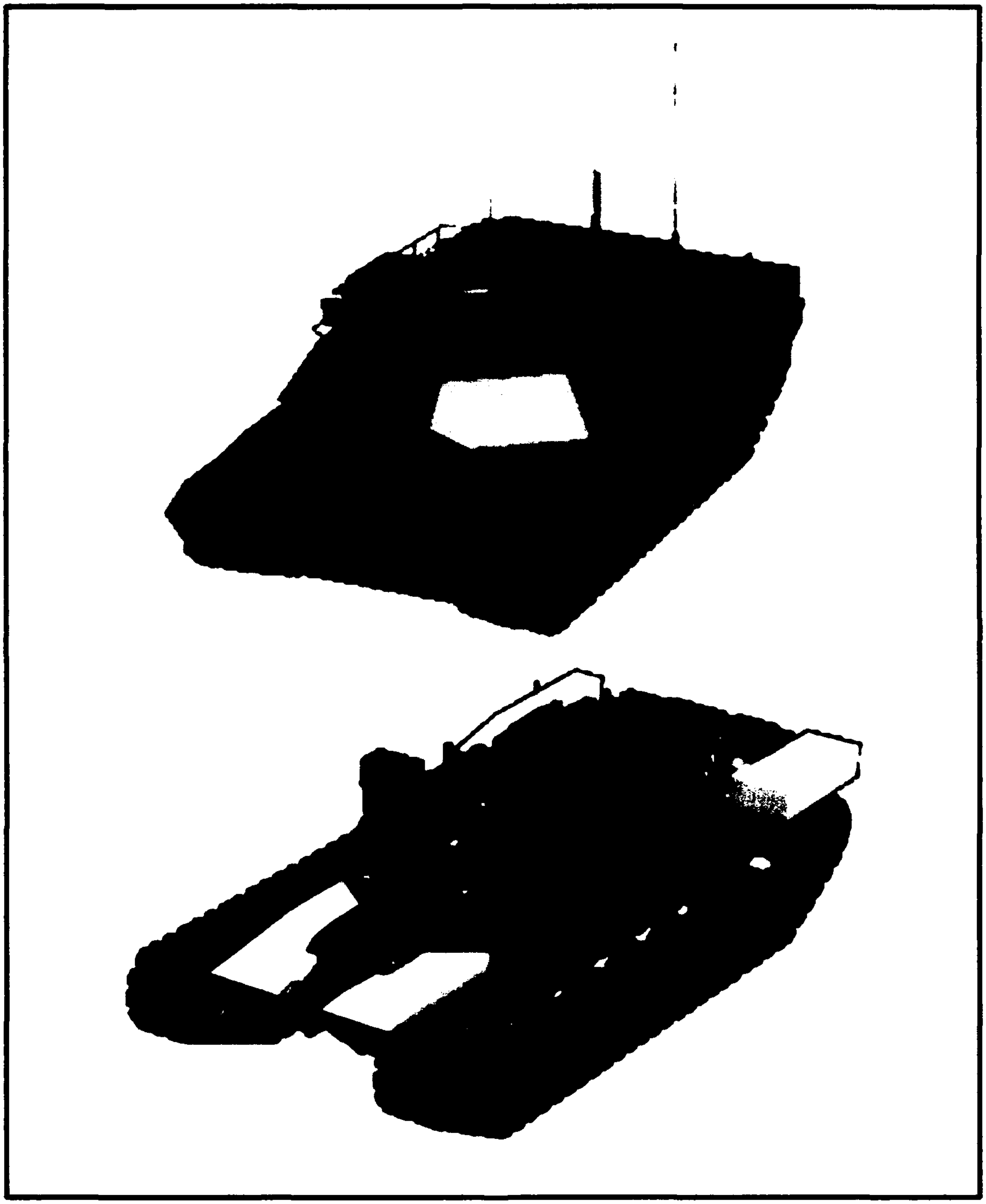

Figure 9. Exterior and Interior Views of the M1.

and (8) a kill/no–kill assessment of a critical component from the effects of the number of spall fragments impacting the component. The details on the distributional forms and parameters for these random variables are well documented [5, 9].

SQuASH output for repeated sampling at a given threat impact location includes the distribution of damage vectors (representing the functional/non–functional capabilities of all critical components), the probabilities of perforating armor, the distribution of residual penetration, and the probabilities of kill for individual components. For a DAL–type of SQuASH analysis, the output also includes the distribution of M LoFs, the distribution of F LoFs, and the distribution of vehicle P_ks. For a DS–type of analysis, the output includes the distributions of degraded states.

As mentioned in the introduction, SQuASH is in the process of being implemented under the Modular UNIX®–based Vulnerability Estimation Suite (MUVES) [6–8]. The purpose of MUVES is to incorporate V/L codes into a single framework such that the software is well–designed for the spectrum of V/L models, incorporates the latest in software technologies, shares common algorithms among the V/L codes, provides an audit trail of V/L analyses, and facilitates the management and archiving of V/L analyses. The compartment–level model is already implemented under MUVES but is under continual development as new algorithms are added to handle recent technologies for AFVs and munitions. SQuASH was identified as the second V/L model to be implemented under the MUVES environment for many reasons. One of the principle advantages of implementing it next is that a point–burst component model is, in fact, a subset of a stochastic–point burst model. Given the similar input requirements between these two types of V/L models and the current as well as planned availability of additional computing resources, stochastic point–burst analyses are likely to be performed more than deterministic point–burst analyses. When expected–value outputs are required, SQuASH will be run with the same algorithms but in a deterministic mode. When the initial SQuASH implementation is completed, the compartment and stochastic point–burst codes will for the first time use the same code for V/L algorithms and general purpose areas wherever feasible.

Figure 10 summarizes the salient characteristics of the SQuASH model at its present state of development as implemented independently from MUVES. This figure also succinctly completes the comparisons of the compartment, point–burst, and stochastic point–burst methodologies.

4. Investigations Toward Improved V/L Methodologies

4.1. Revising Compartment Model Damage Correlation Curves Based on SQuASH Model

One possible method for updating the compartment model to reflect new component technology is to use the stochastic point–burst model as a surrogate for field testing. From the Monte Carlo runs the present correlation curves could be updated, or new curves could be developed that would better predict LoF/P_k for modern vehicles. Mr. Aivars Ozolins [13] demonstrated this approach.

This, however, has not been employed since it proves unsatisfactory due to the large inherent statistical variability about the curves. Such errors cannot be adequately accounted for when considering only one independent variable, which is the way that damage correlation curves are currently modeled. The combination of the LoFs/P_ks for many compartments to compute the overall vehicle LoF/P_k is even more unsatisfactory due to the combination of errors. Rather than updating the correlation curves which have very poor goodness–of–fit properties, a different approach is being investigated as discussed in Section 4.2.

Model Applications

- LFT pre–shot predictions.
- LFT post–shot analysis.
- Spare parts requirements for repair of battle damage.
- Implications for low–level V/L models from statistical analyses of model outputs.
- Inputs to war games for some AFVs.

Model Inputs

- Detailed 3–D solid geometric model of the AFV.
- AFV–specific armor properties.
- AFV–specific critical component $P_{k|h}$s.
- Criticality analysis for detailed AFV geometric description.
- Threat performance and capabilities.
- Threat impact location(s) on the AFV.
- DAL or DS fault trees for detailed AFV geometric description.
- BAD including Direct Lethality algorithms if available.

Methodologies Applied

- Geometric ray–tracing techniques.
- Penetration algorithms:
  - For KE munitions: THOR, Grabarek, other specialized algorithms.
  - For SC rounds: Fireman–Pugh, DSM.
- BAD including Direct Lethality models and critical component $P_{k|h}$s.
- Improved Kokinakis–Sperrazza personnel incapacitation.
- DAL or Degraded States.

Random Variables

- Threat's impact location on the AFV.
- Penetration capability of a KE munition on initial impact.
- Residual penetration capability of a KE.
- Initial penetration depth of a SC jet.
- Spatial characterization of spall.
- Number of lethal spall fragments.
- Kill/no–kill assessment of critical component from the effect of KE penetrator, KE penetrator fragment(s), or a SC jet.
- Kill/no–kill assessment of critical component from the effect of the number of spall fragments impacting the component.

Model Outputs

- Probabilities of perforating exterior armors.
- Distribution of residual penetration capabilities.

Figure 10. Summary of SQuASH's Salient Characteristics.

Model Outputs continued

- Distributions of M LoF, F LoF, M/F LoFs, and P_ks.
- Combat–weighted averages of LoFs/P_ks using view, aim dispersion, target exposure, weapon bias, and range.
- Graphical plots and tabular summaries.
- Distribution of damage vectors including personnel.
- Critical component average kill probabilities.
- System average kill probabilities.
- Average personnel incapacitation.
- Distribution of degraded states.

Advantages

- Does not require correlation curves based on full–scale experiments.
- Able to investigate component trade–offs.
- Can provide inputs for spare part analyses.
- Most realistic V/L model for AFVs in terms of modeling physical interactions and geometry.
- Input requirements similar to VAST.
- Only V/L model which outputs the distribution of component damage vectors which are field observable and can be used for model validation.
- Better models certain mechanisms:
  - explicitly models the shattering of KE penetrators.
  - explicitly models deflection of KE penetrators.
  - implicitly accounts for hydraulic ram effects for fuel tanks.
  - explicitly models blast effects of SC jets on suspension components.
- Random variation accounts for AFV geometry, jet/penetrator capabilities, spall characterization, and critical component kill assessments.
- No loss of information; full range of possible outcomes.
- Unbiased estimates of expectation if mean values are the desired outputs.
- Information available for decision making on the basis of evaluating the distribution of outcomes for different AFVs or their variants.
- Being incorporated under the MUVES environment.

Disadvantages

- No direct code linkage to other V/L models at present.
- Input requirements exceed the requirements of the compartment model.
- Does not model ricochet, shock, toxic fumes, fires, or spall effects from secondary/tertiary sources.
- Fault tree analysis assumes independent probability values.
- BAD data required for every target/threat combination.
- Computation–intensive code with long analysis run times.

Figure 10. Summary of SQuASH's Salient Characteristics. (Continued)

4.2. New Simplified–Model Approach

For an investigation of Degraded States versus the Damage Assessment List methodologies, a full–factorial set of computer runs were made using the high–resolution stochastic model (SQuASH) [12]. The factors and levels for the runs on a single vehicle were as follows:

- Exposures
  - Fully Exposed
  - Hull Defilade
- Azimuths
  - 0°
  - 30°
  - 60°
  - 90°
- Threats
  - Large overmatching KE
  - Marginal overmatching KE
- Threat Delivery Errors (foot sigma)
  - 1
  - 2
  - 3
  - 5
  - 10
- Ranges (km)
  - 0.5
  - 1.0
  - 1.5
  - 2.0
  - 2.5
  - 3.0
- Methodologies
  - DAL
  - Degraded States

All levels of the factors were treated qualitatively as indicator variables (categories) and not quantitatively. The outputs from the SQuASH runs were M LoF and F LoF using DAL methodology, a hardware–only aggregation and all–component aggregation using DS methodology (no degradation versus any degradation), and probability of catastrophic kill.

An analysis of variance (ANOVA) was performed on this data examining the effects of the factors (main effects) and all two–way interactions between the main effects. Analysis of variance can be performed in a number of ways to obtained the specific information desired. In addition to testing for significant differences among levels of the factors, the analysis was set up using a regression approach and multiple classification analyses [31] so that we could determine if regression is a viable approach for developing a simplified model from our high–resolution stochastic model. The measure of interest is the goodness–of–fit for the regression, the R^2 value, that indicates the variance in the dependent variable "accounted for" by all factors and covariates in the design. R^2 is always a value between 0 and 1 and is used as the percent variation for which the model accounts, where the larger the value the better the fit. If 100% of the variation within a model can be accounted for, then it is a perfect model.

The R^2 for M LoF was .804 indicating that the regression model accounted for approximately 80% of the variability. The R^2 for F LoF was .771 indicating that the regression model accounted for approximately 77% of the variation. These values are very encouraging. As stated above, all levels of the factors were treated as qualitative variables. If the quantitative information associated with some factors were used (such as striking velocity, projectile diameter, *etc.*), it is expected that a regression model could be identified to better fit the data (the R^2 would increase). Additionally, since these data were generated for another purpose, namely to compare DAL and DS methodologies, no attempt was made to optimize the generation of data for model building. Efforts in this area could also improve the regression model and its goodness–of–fit. Future efforts in this area will be discussed in Section 5.

4.3. Sensitivity Analysis of the Compartment Model

Recommendations of a Peer–Review Group established by the Deputy Under Secretary of the Army for Operations Research in 1989 (Board on Army Science and Technology 1989) [32] resulted in the creation of a Sensitivity Analysis Team whose objectives are as follows:

- match vulnerability models to users' needs,
- define most sensitive parameters influencing vulnerability estimates,
- identify promising areas of vulnerability model research,
- estimate parameter levels at which small variations cause significant effects, and
- conduct series of sensitivity analyses for different models and targets.

It was decided to initially examine the sensitivity of the analysis parameters used in the compartment–level model, since it is the principle model used to develop vulnerability estimates for force–on–force simulations. Two studies were conducted, the first concerning target symmetry and the second concerning cell size for ray–tracing the target [33]. A study of the sensitivity of the compartment model to threat parameters is currently being performed.

The compartment model is generally run at azimuths from 0° to 180° in 30° increments. The results for the right side of the target are assumed equivalent to the corresponding results from the left side. This assumption was tested by examining the results of both KE and SC munitions against the M1 at azimuths from 0° to 330° in 30° increments; compartments (such as ammunition) in the M1 are asymmetric.

Statistical analyses of the model output indicated that target symmetry, while possibly valid for some target vehicles, should not be assumed. This implies that the vulnerability analyst should closely examine each target description used for a compartment–level analysis. Since statistical tests are time consuming, it is recommended that analysts take the conservative approach of assuming asymmetry unless there is substantial evidence to the contrary. This requires that azimuthal angle analyses on both sides of the AFV be performed separately. If the end–users of compartment model analyses are unable to use data for azimuthal angles on both sides of the AFV, then it is recommended that they consider averaging LoF/P_k values for each related pair of angles whose sum is 360° (*e.g.*, 30° and 330°).

Historically, compartment–level studies have used a shotline centered on a grid cell of 4in by 4in or 100mm by 100mm to ray–trace most target descriptions. Given the size of the compartments, it seemed reasonable to consider a coarser grid, thereby lessening the burden on computer resources and ultimately providing a more timely response. The same threats and target were used as in the symmetry study. Grid cells as coarse as 12in by 12in were considered. Statistical analyses of the model output indicated that grid cells could be larger without significantly changing the overall view averages. Since the vehicle examined was modeled in unusually great detail for a compartment–level analysis, this conclusion should hold for most vehicles. These results appear compatible with those of an earlier study that demonstrated the relationship between cell size and the width of confidence intervals about the overall view average [34].

Decisions on both symmetry and optimum cell size should remain in effect any time the particular AFV is evaluated with a compartment–level model. Investigating azimuths around the vehicle will require additional resources, but that amount can be minimized or even eliminated by using a coarser grid throughout the study. For example, for the M1, sampling 6in cells at 30° increments from 0° through 330° would require only 80% of the number of ray traces that would be necessary to sample 4in cells at 30° increments from 0° through 180°. Based on this result, if statistical tests cannot be performed in a timely manner, then a cell size of 6in by 6in is recommended.

Another important finding from this report was the realization that the number of distinct values for M LoF, F LoF, and P_k was very small. There is a discreteness in using the damage correlation curves which results in a tendency for the same outcomes to appear over and over again. Examining results for SC rounds using three different cell sizes at azimuthal angles completely around the vehicle, 65% of the F LoF occurrences were represented by only nine distinct values. This increased to 75% for M LoF and 88% for P_k. These percentages increased even more substantially (all greater than 90%) for the KE threats, which were still represented by less than ten distinct values. This strongly suggests the feasibility of developing a new simplified low–level model.

4.4. SQuASH Validation

Model validation is inexact in that each simulation code requires a set of empirical data (including inputs and outputs) for comparison with model inputs and outputs, as well as statistical analyses to quantify differences and to provide some measures of confidence in the model. In performing model validation we are actually checking for consistency (in some sense) with these empirical data. Validation should only be performed after the code has been verified, *i.e.*, determined to accurately read input, correctly compute, and output results as intended. The inherent characteristics of a model necessitate that the validation process is unique for every simulation model and its associated code [35].

A broad set of empirical data must be collected, with collection limited by factors such as technology and resources. Validation of a code/model is restricted to the bounds of the empirical data. The relationships among model inputs may be simple but are more than likely complex or even unquantifiable. Internal computations in the code may be deterministic or randomized. Model outputs may be independent or correlated, univariate or multivariate, *etc.* Tools to compare collected data against code predictions may be accomplished by tabular summaries or visual representations. All statistical techniques require assumptions. Each is also designed to answer a specific question. Therefore, a set of appropriate statistical techniques are most likely required to satisfactorily quantify differences and to measure the ability of the code to predict outcomes. In some situations, appropriate statistical techniques may not exist, and basic research may be required to develop highly specialized statistical tests.

Validation is a continuing process. As more empirical data are collected and as additional statistical tests are performed, the level of confidence in a code is expected to increase. At some point during this process, the introduction of more empirical data provides a minimal contribution to the overall measures of confidence in the model. It is at this point that the model and its corresponding code is usually considered validated for the range of the empirical data.

The component damage prediction capability of SQuASH and the application of SQuASH to the development of a new low-resolution model stress the importance of validating the SQuASH code. Statistical hypothesis tests have been utilized to compare empirical data from the M1 LFT and predicted SQuASH outcomes[36-39]. These tests were performed after a preliminary examination which confirmed reasonable agreement between LFT observables and the SQuASH predictions [37]. The BVLD currently has a contract to perform statistical analyses on LF data for several AFVs. Statistical analyses to date have been limited by the fact that LFTs are not designed for the purpose of validating SQuASH. Analyses have been hampered by small sample sizes and restrictions on statistical analysis assumptions.

The Modified Ordering by Probabilities (OP) test [39] has been the preferred method to date for comparing component damage vectors, both over the entire vehicle and for various subsystems of the AFV.[5] The null hypothesis for the test is that the distribution of SQuASH component damage vectors is identical to the distribution of observed live-fire component damage vectors. For each LF shot, a Modified OP test is performed to determine whether or not the observed LF outcome falls in the tail of the distribution defined by a 1000 SQuASH replications. If the LF outcome appears in the tail of the SQuASH predicted distribution, then it is considered a rare event and the null hypothesis of equal distributions is rejected for the particular shot. If the LF outcome does not appear in the tail, then the test fails to reject the null hypothesis.

After applying the Modified OP test to each LF shot, there is a collection of successes and failures for the **n** shots, where each represents a Bernoulli trial. The **n** results compose a binomial distribution with an associated probability of success. There is also an expected number of trial rejections even if the null hypothesis was true. The maximum number of failures allowed before the null hypothesis is unconditionally rejected can be tested by a second hypothesis test. This hypothesis test provides a confidence level that the parameter of the binomial distribution, *i.e.*, the probability of success, equals a specific value which is the designated acceptance level of the first hypothesis test. If this hypothesis is rejected, then the only explanation is that the original null hypothesis was in error; that is, the distributions are not equivalent.

In the application of the Modified OP test, it is assumed that 1000 replications of the SQuASH code for each LF shot are sufficient to represent the distribution of component damage vectors. Statistically validating this assumption has proven difficult. If simplifying assumptions are made, then estimates for the number of times the shot must be replicated can be computed. The output from these theoretical computations is expressed in terms of confidence that a certain percentage of the distribution of the damage state vectors has been observed. Such theoretical computations are tractable when complete damage to all components is assumed to be equal 0.50, or when complete damage to all components is assumed to be equivalent but unequal to 0.50. A better formula or means for computing estimates in other cases is being researched [41].

Statistical comparisons between selected LFT shots and SQuASH predictions of component damage are expected to be completed for several AFVs by the end of FY93 under the aforementioned government contract. The BVLD plans to pursue a follow-on effort in FY94-95 to evaluate and to incorporate the contractor's suggested modifications into SQuASH.

[5] A report by the Institute for Defense Analysis [40] outlined some tests which are better than the Modified OP test in some respects; however, they fall short in others. These tests have not been applied to LF data and SQuASH output to date. A recent contractor to the BVLD has also proposed other procedures. These procedures are not yet well defined, have limitations, and have not been applied.

5. Recommendations

An underlying assumption of any deterministic expected–value model is that the processes dependent on random variables can be adequately simulated by replacing random variables with a measure of central tendency of the underlying distribution during some phase of the modeling process. A loss of information is incurred when the distribution of a random variable is suppressed. The range of possible outcomes is lost, and the model is more sensitive to minor changes in input. These limitations have been shown in both the VAMP and VAST models.

Despite the inherent limitations of existing compartment models, there will always be a need for this type of model in the hierarchy of vulnerability models since vulnerability/survivability estimates are essential to concept vehicle studies. Thus, it is crucial that a compartment–level model provide good, expeditious predictions.

Weighing VAST's limitations, analysis inputs, and its run time against those of SQuASH, we recommend that SQuASH be used instead of VAST for a component–level analysis when feasible. We strongly encourage our component–level customers to use MOP metrics and not MOE metrics as a starting point for their studies. MOE metrics produced on the DAL methodology "averages" out effects such as scenario conditions, tactical doctrines, *etc.* MOPs provide more detailed V/L information that our customers can incorporate into their simulation codes or which they can map to the MOE space based on their requirements.

The Board of Army Science and Technology (BAST) stated in its 1989 report on vulnerability analysis [32] that the current hierarchy of vulnerability models is incomplete and misdirected. The BAST indicated that the development of more detailed vulnerability models was a wasted effort. They suggest concentration on the lower–end models, more simple than even the compartment–level model.

A recent survey of the community of V/L users was conducted to investigate these recommendations [42]. The opinions expressed by the surveyed users indicated that the existing hierarchy of AFV V/L models and methodologies meet their requirements. The majority of user suggestions focused on the need to improve documentation, databases, code maintenance of older V/L codes, and tool capabilities/interfaces. Of the offered suggestions, only two state requirements for methodology improvements. One seeks a way to credit novel survivability practices which afford good vulnerability reductions in the low–end V/L models, and the other seeks confidence–type metrics on vulnerability estimates. Distributions of degraded states metrics can be used to provide one class of confidence metrics. The paucity of methodology suggestions in this survey stresses the importance of having a group dedicated to fostering methodology research and development.[6]

Although the recent survey of BVLD's community of end–users did not identify needs to concentrate on low–end V/L models, we endorse such actions in accordance with the BAST recommendations. However, contrary to the BAST recommendations, we assert that continued development of the highest–resolution model and its validation are critical to the development of a new, low–resolution, V/L model. SQuASH provides cost–effective alternative to costly V/L tests and provides a mechanism for identifying areas in the model which would most greatly benefit from field testing.

One of the current limitation of the existing hierarchy of V/L models for AFVs is there is no direct linkage between the models, other than the algorithms which they share. We recommend using output from the SQuASH model based on LFT&E data and sensitivity analyses to develop a regression model which would become the new low–end model for vulnerability assessments [targeted for FY95–97]. By using results from the highest resolution model to assist in the construction of the lowest level model, we assert a more accurate compart-

[6] The mission for the Survivability/Lethality Analysis Directorate (SLAD) of the US Army Research Laboratory (ARL) includes the design, development, operation, and maintenance of the requisite tools, techniques, and methodologies to support the Army's survivability/lethality/vulnerability analysis program requirements.

ment–level type of model can be derived. A regression approach also offers the advantage that measures on the goodness of fit of the model can be statistically quantified. A difficulty to overcome with this approach is the development of a procedure for incorporating hit location so that customers can continue to receive post–processed data as a function of aim point, weapon bias, and munition dispersion.

In FY93, a regression analysis will be performed on aggregated degraded states probabilities for several armored combat vehicles, selected munitions, and the associated sets of initial conditions (*e.g.*, range, dispersion, azimuth, exposure). The analysis will identify important variables for development of a new low–level vulnerability model calibrated with the highest resolution V/L model.

In FY93, we will also begin working with a pre–production release of the stochastic point–burst model as implemented under the MUVES environment. Using knowledge acquired from our sensitivity analyses of the compartment model, the ANOVA of DS versus DAL methodologies, and the FY93 regression analyses, we will concentrate on identifying desirable model outputs and designing a series of SQuASH runs to facilitate the eventual development of new low–resolution model.

Enhancement, verification, and validation of SQuASH is critical to LFT&E analyses and spare parts requirement analyses. It is also important for degraded states research as well as low–level V/L model development. During FY92–93, statistical comparisons between selected LFT shots and SQuASH predictions of component damage are being done under contract. The significance of differences will be noted, and reasons for the differences will be investigated. A follow–on effort in FY94–95 will be required by BVLD to evaluate and to incorporate suggested modifications into SQuASH and its associated model inputs.

6. References

[1] "Tripartite Anti−Tank Trials and Lethality Evaluation, Part I," Canadian Armament Research and Development Establishment, CARDE Report 0−21, November 1959.

[2] C. L. Nail and T. E. Bearden, "Vulnerability Analysis Methodology Program (VAMP): A Combined Compartment−Kill Vulnerability Model," CSC TR−79−5585, Computer Sciences Corporation, Huntsville, AL, October 1979.

[3] C. L. Nail, "Vulnerability Analysis for Surface Targets (VAST) − An Internal Point−Burst Vulnerability Model," CSC TR−78−5538, Computer Sciences Corporation, Huntsville, AL, September 1978, UNCLASSIFIED.

[4] C. L. Nail, "Vulnerability Analysis for Surface Targets (VAST) − An Internal Point−Burst Vulnerability Assessment Model−−Revision I," CSC TR−82−5740, Computer Sciences Corporation, Huntsville, AL, developed under DAAK11−81−C−0006 (Task 002), August 1982, UNCLASSIFIED.

[5] A. Ozolins, "Stochastic High−Resolution Vulnerability Simulation for Live−Fire Programs," *The Proceedings of the Tenth Annual Symposium on Survivability and Vulnerability of the American Defense Preparedness Association*, May 1988, UNCLASSIFIED.

[6] P. J. Hanes, K. R. Murray, D. A. Gwyn, and H. R. Polak, "An Overview and Status Report of MUVES (Modular UNIX−based Vulnerability Estimation Suite)," BRL−MR−3679, US Army Ballistic Research Laboratory, Aberdeen Proving Ground, MD, July 1988, UNCLASSIFIED.

[7] P. J. Hanes, S. L. Henry, G. S. Moss, K. R. Murray, and W. A. Winner, "Modular UNIX®−based Vulnerability Estimation Suite (MUVES) Analyst's Guide," BRL−MR−3954, US Army Ballistic Research Laboratory, Aberdeen Proving Ground, MD, December 1991, UNCLASSIFIED.

[8] P. J. Hanes, S. L. Henry, G. S. Moss, K. R. Murray, and W. A. Winner, "Modular UNIX®−based Vulnerability Estimation Suite (MUVES) Analyst's Guide − Appendix B: 'Compart' Approximation Method," BRL−MR−3955, US Army Ballistic Research Laboratory, Aberdeen Proving Ground, MD, December 1991, UNCLASSIFIED.

[9] P. H. Deitz and A. Ozolins, "Computer Simulations of the Abrams Live−Fire Field Testing," BRL−MR−3755, US Army Ballistic Research Laboratory, Aberdeen Proving Ground, MD, May 1989, UNCLASSIFIED.

[10] M. W. Starks, "New Foundations for Tank Vulnerability Analysis," *The Proceedings of the Tenth Annual Symposium on Survivability and Vulnerability of the American Defense Preparedness Association*, May 1988, UNCLASSIFIED.

[11] J. M. Abell, L. K. Roach, and M. W. Starks, "Degraded States Vulnerability Analysis," BRL−TR−3010, US Army Ballistic Research Laboratory, Aberdeen Proving Ground, MD, June 1989, UNCLASSIFIED.

[12] J. M. Abell, M. D. Burdeshaw, and B. A. Richter, "Degraded States Vulnerability Analysis: Phase II," BRL−TR−3161, US Army Ballistic Research Laboratory, Aberdeen Proving Ground, MD, October 1990, UNCLASSIFIED.

[13] P. H. Deitz, M. W. Starks, J. H. Smith, and A. Ozolins, "Current Simulation Methods in Military Systems Vulnerability Assessment," Army Operations Research Symposium XXXIX, Ft. Lee, VA, 10−11 October 1990, UNCLASSIFIED.

[14] J. R. Rapp, "An Investigation of Alternative Methods for Estimating Armored Vehicle Vulnerability," ARBRL−MR−03290, US Army Ballistic Research Laboratory, Aberdeen Proving Ground, MD, July 1983, UNCLASSIFIED.

[15] R. DiPersio and J. Simon, "The Theory of Residual Penetration by Ideal Shaped−Charge Jets," BRL 1313, US Army Ballistic Research Laboratory, Aberdeen Proving Ground, MD, March 1966, UNCLASSIFIED.

[16] R. DiPersio, J. Simon and A. B. Merendino, "Penetration of Shaped−Charge Jets into Metallic Targets," BRL 1296, US Army Ballistic Research Laboratory, Aberdeen Proving Ground, MD, September 1965, UNCLASSIFIED.

[17] R. DiPersio and J. Simon, "The Penetration–Standoff Relation of Idealized Shaped–Charge Jets," BRL 1542, US Army Ballistic Research Laboratory, Aberdeen Proving Ground, MD, February 1964.

[18] A. Ozolins, "Compilation of VAMP Damage Evaluation Procedures, Target–Threat Interaction Algorithms, and Associated Numerical Approximations," US Army Ballistic Research Laboratory, Aberdeen Proving Ground, MD, unpublished, 5 March 1987.

[19] C. Grabarek, "Penetration of Armor by Steel and High Density Penetrators," BRL 2134, US Army Ballistic Research Laboratory, Aberdeen Proving Ground, MD, October 1971.

[20] S. B. Segletes, "A Model of the Effects of Traverse Velocity on the Penetration of a Shaped–Charge Jet," BRL–MR–3409, US Army Ballistic Research Laboratory, Aberdeen Proving Ground, MD, November 1984.

[21] K. Frank, "Armor–Penetrator Performance Measures," ARBRL–MR–03097, US Army Ballistic Research Laboratory, Aberdeen Proving Ground, MD, March 1981, UNCLASSIFIED.

[22] R. L. Kirby, "Appendix F, A New Crew Compartment Algorithm for the Compartment Vulnerability Model," US Army Ballistic Research Laboratory, Aberdeen Proving Ground, MD, 15 May 1987, unpublished, UNCLASSIFIED.

[23] L. R. Kruse and P. L. Brizolara, "An Analytical Method for Deriving Conditional Probabilities of Kill for Target Components," BRL 1563, US Army Ballistic Research Laboratory, Aberdeen Proving Ground, MD, December 1971.

[24] R. Shnidman, "Direct Fragment Lethality Inference from Witness Plate Array Data," *The Proceedings of the Tenth Annual Symposium on Survivability and Vulnerability of the American Defense Preparedness Association*, May 1988, SECRET.

[25] G. R. Comstock, "The Degraded States Weapons Research Simulation (DSWARS): An Investigation of the Degraded States Vulnerability Methodology in a Combat Simulation," AMSAA–TR–495, US Army Materiel Systems Analysis Activity, Aberdeen Proving Ground, MD, February 1991.

[26] P. H. Deitz, T. M. Muehl, S. L. Henry, G. S. Moss, E. O. Davisson, and S. A. Coates, "Synthesized CAD Methods for Combat Vehicle Survivability Analysis," BRL–MR–3883, US Army Ballistic Research Laboratory, Aberdeen Proving Ground, MD, December 1990, UNCLASSIFIED.

[27] T. F. Hafer, "The SHUTE Internal Point–Burst Vulnerability Assessment Program," *Proceedings of the Second Symposium on Vulnerability and Survivability, Volume II – Methodology, Sea Targets, Air Targets, Land Targets*, January 1977, SECRET.

[28] "The Resistance of Various Metallic Materials to Perforation by Steel Fragments; Empirical Relationships for Fragment Residual Velocity and Residual Weight," Ballistic Analysis Laboratory, Project THOR, The Johns Hopkins University, Baltimore, MD, Technical Report No. 47, developed under DA–36–034–509–ORD–29RD, April 1961, CONFIDENTIAL.

[29] "The Resistance of Various Non–Metallic Materials to Perforation by Steel Fragments; Empirical Relationships for Fragment Residual Velocity and Residual Weight," Ballistic Analysis Laboratory, Project THOR, The Johns Hopkins University, Baltimore, MD, Technical Report No. 51, developed under DA–36–034–509–ORD–29RD, April 1963, CONFIDENTIAL.

[30] W. Kokinakis and J. Sperrazza, "Criteria for Incapacitating Soldiers with Fragments and Flechettes," BRL 1269, US Army Ballistic Research Laboratory, Aberdeen Proving Ground, MD, January 1965, SECRET.

[31] *SPSS–X User's Guide*, Third edition, SPSS Inc., Chicago, IL, 1988, pp. 365–378, UNCLASSIFIED.

[32] Board of Army Science and Technology, Commission on Engineering and Technical Systems, National Research Council, "Armored Combat Vehicle Vulnerability to Anti–Armor Weapons: A Review of the Army's Assessment Methodology," National Academy Press, Washington, D.C., 1989, UNCLASSIFIED.

[33] W. A. Winner, J. C. Collins III, W. E. Baker, J. H. Smith, and E. A. Laurie, "Sensitivity Analysis of .e Compartment Model to Cell Size and Symmetry for the Abrams Vehicle," BRL–MR–3963, US Army Ballistic Research Laboratory, Aberdeen Proving Ground, MD, July 1992, SECRET.

[34] M. S. Taylor and B. A. Bodt, "Construction of Approximate Confidence Intervals for Probability-of-Kill Via the Boc.strap," ARBRL-TR-02570, US Army Ballistic Research Laboratory, Aberdeen Proving Ground, MD, July 1984, UNCLASSIFIED.

[35] W. E. Baker and M. S. Taylor, "A Nonparametric Statistical Approach to the Validation of Computer Simulation Models," BRL-TR-2696, US Army Ballistic Research Laboratory, Aberdeen Proving Ground, MD, November 1985, UNCLASSIFIED.

[36] D. W. Webb, "Tests for Consistency of Vulnerability Models," BRL-TR-3030, US Army Ballistic Research Laboratory, Aberdeen Proving Ground, MD, August 1989, UNCLASSIFIED.

[37] C. J. Dively, S. L. Henry, J. H. Suckling, J. H. Smith, W. E. Baker, D. W. Webb, and P. H. Deitz, "Abrams Live Fire Test Program: Comparison Between SQuASH Predictions and Field Outcomes (U)," BRL-SP-81, US Army Ballistic Research Laboratory, Aberdeen Proving Ground, MD, August 1989, SECRET.

[38] P. H. Deitz, J. H. Smith, and J. H. Suckling, "Comparison of Field Tests with Simulations: Abrams Program Lessons Learned," Proceedings of the XXVIII Annual Meeting of the Army Operations Research Symposium, 11-12 October 1989, Fort Lee, VA, pp 108-128; also BRL-MR-3814, US Army Ballistic Research Laboratory, Aberdeen Proving Ground, MD, March 1990, UNCLASSIFIED.

[39] W. E. Baker, and D. W. Webb, "Applying Statistical Tests to Examine Consistency Between Abrams Live-Fire Data and SQuASH Simulation Output (U)," BRL-TR-3109, US Army Ballistic Research Laboratory, Aberdeen Proving Ground, MD, June 1990, SECRET.

[40] L. Tonnessen, A. Fries, L. Starkey, and A. Stein, "Live Fire Testing in the Evaluation of the Vulnerability of Armored Vehicles and Other Exposed Land-Based Systems," Institute for Defense Analyses, Alexandria, VA, July 1989, SECRET.

[41] W. E. Baker, D. W. Webb, and L. D. Losie, "Sampling Problems Pertaining to the Number of Replications for the Stochastic Simulation Models," Proceedings of the Thirty-eighth Conference on the Design of Experiments in Army Research, Development and Testing, sponsored by the Army Research Office, 28-30 October 1992, in preparation.

[42] J. T. Klopcic, "Survey of Vulnerability Methodological Needs," BRL-SP-93, US Army Ballistic Research Laboratory, Aberdeen Proving Ground, MD, November 1991, UNCLASSIFIED.

INTENTIONALLY LEFT BLANK.

List of Symbols, Abbreviations, and Acronyms

AFV	Army Fighting Vehicle
ANOVA	Analysis of Variance
ARL	US Army Research Laboratory
BAD	Behind–Armor Debris
BRL	US Army Ballistic Research Laboratory
BVLD	Ballistic Vulnerability/Lethality Division
CARDE	Canadian Armament Research and Development Establishment
COEA	Cost and Operational Effectiveness Analysis
DAL	Damage Assessment List
DL	Direct Lethality
DS	Degraded States
DSM	DiPersio, Simon, Merendino
F LoF	Firepower Loss–of–Function
FIFV	Future Infantry Fighting Vehicle
KE	Kinetic Energy
LFT	Live–Fire Test
LFT&E	Live–Fire Test and Evaluation
LoF	Loss–of–Function
M LoF	Mobility Loss–of–Function
MAA	Mission Area Analysis
MOE	Measure of Effectiveness
MOP	Measure of Performance
MUVES	Modular UNIX®–based Vulnerability Estimation Suite
OP	Ordering by Probabilities
$\mathbf{P_k}$	Probability of a Catastrophic Kill
$\mathbf{P_{k\|h}}$	Probability of a Catastrophic Kill Given a Hit
SC	Shaped–charge
SHUTE	Spall Handling Universal Threat Evaluation
SQuASH	Stochastic Quantitative Assessment of System Hierarchies
V/L	Vulnerability/Lethality
VAMP	Vulnerability Assessment Methodology Program
VAST	Vulnerability Analysis for Surface Targets

INTENTIONALLY LEFT BLANK.

No. of Copies	Organization
2	Administrator Defense Technical Info Center ATTN: DTIC-DDA Cameron Station Alexandria, VA 22304-6145
1	Commander U.S. Army Materiel Command ATTN: AMCAM 5001 Eisenhower Ave. Alexandria, VA 22333-0001
1	Director U.S. Army Research Laboratory ATTN: AMSRL-D 2800 Powder Mill Rd. Adelphi, MD 20783-1145
1	Director U.S. Army Research Laboratory ATTN: AMSRL-OP-CI-AD, Tech Publishing 2800 Powder Mill Rd. Adelphi, MD 20783-1145
2	Commander U.S. Army Armament Research, Development, and Engineering Center ATTN: SMCAR-IMI-I Picatinny Arsenal, NJ 07806-5000
2	Commander U.S. Army Armament Research, Development, and Engineering Center ATTN: SMCAR-TDC Picatinny Arsenal, NJ 07806-5000
1	Director Benet Weapons Laboratory U.S. Army Armament Research, Development, and Engineering Center ATTN: SMCAR-CCB-TL Watervliet, NY 12189-4050
(Unclass. only) 1	Commander U.S. Army Rock Island Arsenal ATTN: SMCRI-IMC-RT/Technical Library Rock Island, IL 61299-5000
1	Director U.S. Army Aviation Research and Technology Activity ATTN: SAVRT-R (Library) M/S 219-3 Ames Research Center Moffett Field, CA 94035-1000

No. of Copies	Organization
1	Commander U.S. Army Missile Command ATTN: AMSMI-RD-CS-R (DOC) Redstone Arsenal, AL 35898-5010
1	Commander U.S. Army Tank-Automotive Command ATTN: ASQNC-TAC-DIT (Technical Information Center) Warren, MI 48397-5000
1	Director U.S. Army TRADOC Analysis Command ATTN: ATRC-WSR White Sands Missile Range, NM 88002-5502
1	Commandant U.S. Army Field Artillery School ATTN: ATSF-CSI Ft. Sill, OK 73503-5000
(Class. only) 1	Commandant U.S. Army Infantry School ATTN: ATSH-CD (Security Mgr.) Fort Benning, GA 31905-5660
(Unclass. only) 1	Commandant U.S. Army Infantry School ATTN: ATSH-CD-CSO-OR Fort Benning, GA 31905-5660
1	WL/MNOI Eglin AFB, FL 32542-5000
	<u>Aberdeen Proving Ground</u>
2	Dir, USAMSAA ATTN: AMXSY-D AMXSY-MP, H. Cohen
1	Cdr, USATECOM ATTN: AMSTE-TC
1	Dir, ERDEC ATTN: SCBRD-RT
1	Cdr, CBDA ATTN: AMSCB-CI
1	Dir, USARL ATTN: AMSRL-SL-I
10	Dir, USARL ATTN: AMSRL-OP-CI-B (Tech Lib)

No. of Copies	Organization
10	C.I.A. OIR/DB/Standard GE47 HQ Washington, DC 20505
1	HQDA DAMI-FIT (COL Everson) WASH DC 20310-1001
1	HQDA DAMO-ZD (Mr. Riente) The Pentagon, Rm 3A538 WASH DC 20310-0410
1	HQDA SARD-DO (Mr. Ron Mlinarchik) WASH DC 20310-0102
1	HQDA SARD-DOV (COL Steve Dasher) WASH DC 20310-0103
1	HQDA SARD-TN (LTC Fejfar) The Pentagon, Rm 3E360 WASH DC 20310
1	HQDA SARD-TT (Mr. Mike Clauson) WASH DC 20310-0103
1	HQDA OUSDA(A), DDRE(T&E) ATTN: COL Bernard (Chip) B. Ferguson The Pentagon WASH DC 20301-3110
2	HQDA OUSD(A) DDDRE(R&AT-ET) ATTN: Mr. Rick L. Menz/Dr. James Short The Pentagon, Rm 3D1089 WASH DC 20301-3080
1	HQDA (Limres Study Group) ATTN: Shirley D. Ford The Pentagon, Room 1B929 WASH DC 20310
1	Office of the Assistant Secretary of the Army (Research, Development, and Acquisition) ATTN: LTG Cianciolo, Military Deputy Washington, DC 20310-0100

No. of Copies	Organization
1	Office of the Secretary of the Army (Research, Development, and Acquisition) ATTN: MG Beltson, Deputy for Systems Management Washington, DC 20310-0103
1	Deputy Under Secretary of the Army for Operations Research ATTN: SAUS-OR (Hon Walt Hollis) The Pentagon, Room 2E660 Washington, DC 20310-0102
1	Office of the Deputy Director of Defense, R&E ATTN: Dr. William Snowden The Pentagon, Room 3D359 Washington, DC 20301
1	OUSD(A), ODT&E/LFT ATTN: COL Paul M. Severance, Mil Asst. The Pentagon, Room 3E1060 Washington, DC 20301
2	OUSD(A), ODT&E/LFT ATTN: James O'Bryon, Deputy Director Albert E. Rainis The Pentagon, Rm 3E1060 Washington, DC 20301-3001
1	SAF/AQT (Mr. George Warren) The Pentagon, Rm BE939 Washington, DC 20330-1000
1	Assistant Deputy Under Secretary of the Navy ATTN: Fred Crowson Crystal Plaza 5, Room 162 2211 Jefferson Davis Hwy. Arlington, VA 22202

No. of Copies	Organization
9	Defense Advanced Research Projects Agency ATTN: Mr. B. Bandy Dr. R. Kahn Dr. C. Kelly Mr. P. Losleben Dr. J. Lupo Mr. F. Patten Dr. Reynolds Mr. S. Squires COL J. Thorpe 3701 North Fairfax Drive Arlington, VA 22203-1714
2	Central Intelligence Agency ATTN: ORD/PERD (Ray Cwiklinski) (Tom Kennedy) Washington, DC 20505
1	Central Intelligence Agency ATTN: ORD/IERD (J. Fleisher) Washington, DC 20505
2	Central Intelligence Agency ATTN: OIA (Barbara A. Kroggel) (Monica McGuinn) Washington, DC 20505
1	Central Intelligence Agency ATTN: ORD (Donald Gerson) 1820 N. Fort Myer Drive Arlington, VA 22209
1	Chief of Naval Operations OP-332D ATTN: Mr. Chuck Bogner Rm 4D537, The Pentagon Washington, DC 20350-2000
1	Department of the Navy ATTN: RADM Charles R. McGrail, Jr. Pentagon, Room 4E536 Washington, DC 20350-2000
1	Commander U.S. Army Materiel Command ATTN: AMCDE-PI (Dan Marks) 5001 Eisenhower Avenue Alexandria, VA 22333-0001

No. of Copies	Organization
1	Headquarters U.S. Army Materiel Command ATTN: AMCSI (Dr. R. Chait) 5001 Eisenhower Avenue Alexandria, VA 22333-0001
1	Commander U.S. Army Materiel Command ATTN: AMCPD (Darold Griffin) 5001 Eisenhower Avenue Alexandria, VA 22333-0001
1	Commander U.S. Army Materiel Command ATTN: AMCPD-PT (Alan Elkins) 5001 Eisenhower Avenue Alexandria, VA 22333-0001
1	Commander U.S. Army Research Laboratory ATTN: AMSLC-CT (K. Zastrow) 2800 Powder Mill Road Adelphi, MD 20783-1145
1	Commander U.S. Army Research Laboratory ATTN: AMSLC-CG 2800 Powder Mill Road Adelphi, MD 20783-1145
1	Commander U.S. Army Research Laboratory ATTN: AMSLC-LO (LTC P. J. Fardink) 2800 Powder Mill Road Adelphi, MD 20783-1145
1	Commander U.S. Army Research Laboratory ATTN: SLCLT (LTC Marshall) 2800 Powder Mill Road Adelphi, MD 20783-1145
2	Commander U.S Army Research Laboratory ATTN: AMSLC-TP (J. Predham) (D. Smith) 2800 Powder Mill Road Adelphi, MD 20783-1145

No. of Copies | Organization

1 Commander
U.S. Army Research Laboratory
ATTN: AMSRL-SS-M (Marcos Sola)
2800 Powder Mill Road
Adelphi, MD 20783-1145

1 Commandant
U.S. Army Logistics Management College
ATTN: AMXMC-LS-S (CPT(P) Stephen Parker)
Ft. Lee, VA 23801

1 Director
Combat Development
U.S. Army Transportation School
ATTN: COL Elijah Toney
Ft. Eustis, VA 23604

1 Director
U.S. Army Materials Technology Laboratory
ATTN: SLCMT-ATL
Watertown, MA 02172-0001

3 Director
U.S. Army Research Office
ATTN: SLCRO-MA (Dr. J. Chandra)
(Dr. K. Clark)
(Dr. Wu)
P.O. Box 12211
Research Triangle Park, NC 27709-2211

1 Director
U.S. Army Survivability Management Office
ATTN: SLCSM-C31 (H. J. Davis)
2800 Powder Mill Road
Adelphi, MD 20783

1 Director
U.S. Army Survivability Management Office
ATTN: SLCSM-D (COL H. Head)
2800 Powder Mill Road
Adelphi, MD 20783-1145

1 Commander
U.S. Army Armament Research, Development and Engineering Center
ATTN: SMCAR-CCH-V (Paul H. Gemmill)
Picatinny Arsenal, NJ 07806-5000

No. of Copies | Organization

1 Commander
U.S. Army Armament Research, Development and Engineering Center
ATTN: SMCAR-FSS-E (Jack Brooks)
Picatinny Arsenal, NJ 07806-5000

1 Commander
U.S. Army Armament Research, Development and Engineering Center
ATTN: SMCAR-TD (Jim Killen)
Picatinny Arsenal, NJ 07806-5000

1 Commander
U.S. Army Armament, Research, Development and Engineering Center
ATTN: SMCAR-TDS (Vic Lindner)
Picatinny Arsenal, NJ 07806-5000

1 Commander
Belvoir Research, Development and Engineering Center
ATTN: STRBE-FC (Ash Patil)
Fort Belvoir, VA 22060-5606

1 Commander
Belvoir Research, Development and Engineering Center
ATTN: STRBE-JDA (Melvin Goss)
Fort Belvoir, VA 22060-5606

1 Commander, USACECOM
R&D Technical Library
ATTN: ASQNC-ELC-IS-L-R, Myer Center
Fort Monmouth, NJ 07703-5000

1 Director
Center for Night Vision and Electro-Optics
ATTN: AMSEL-RD-NV-V (John Palmer)
Fort Belvoir, VA 22060-5677

1 Director
Center for Night Vision and Electro-Optics
ATTN: AMSEL-RD-NV-V (John Ho)
Fort Belvoir, VA 22060-5677

No. of Copies	Organization
1	Director Center for Night Vision and Electro-Optics ATTN: AMSEL-RD-NV-D (Dr. R. Buser) Fort Belvoir, VA 22060-5677
1	Commander U.S. Army Foreign Science and Technology Center ATTN: AIFR (Bill Rich) 220 Seventh Street, NE Charlottesville, VA 22901-5396
2	Commander U.S. Army Foreign Science and Technology Center ATTN: MSIC (T. Walker) (R. Wittnebel) 220 Seventh Street, NE Charlottesville, VA 22901-5396
2	Commander U.S. Army Foreign Science and Technology Center ATTN: AIFRS (Gordon Spencer) (Dr. Steven Carter) 220 Seventh Street, NE Charlottesville, VA 22901-5396
1	Commander U.S. Army Foreign Science and Technology Center ATTN: AIFRT (John Kosiewicz) 220 Seventh Street, NE Charlottesville, VA 22901-5396
1	Commander U.S. Army Foreign Science and Technology Center ATTN: AIFRE (S. Eitelman) 220 Seventh Street, NE Charlottesville, VA 22901-5396
1	Commander U.S. Army Harry Diamond Laboratories ATTN: SLCHD-RT (Peter Johnson) 2800 Powder Mill Road Adelphi, MD 20783-1197

No. of Copies	Organization
2	Commander U.S. Army Missile Command ATTN: AMSMI-RD-GC-T (R. Alongi) Redstone Arsenal, AL 35898-5000
1	Commander U.S. Army Missile Command ATTN: AMSMI-RD-SS-AT (Ed Vaughn) Redstone Arsenal, AL 35898-5000
1	Commander U.S. Army Missile Command ATTN: AMSMI-RD (J. Bradas) Redstone Arsenal, AL 35898-5000
1	Commander U.S. Army Missile Command ATTN: AMSMI-YTSD (Glenn Allison) Redstone Arsenal, AL 35898-5070
1	Commander U.S Army Missile Command ATTN: AMSMI-REX (W. Pittman) Redstone Arsenal, AL 35898-5500
1	Director U.S Army Missile and Space Intelligence Center ATTN: AIMS-RT (Pat Jordan) Redstone Arsenal, AL 35898-5500
1	Director U.S. Army Missile and Space Intelligence Center ATTN: AIMS-YLD (Vernon L. Stallcup) Redstone Arsenal, AL 35898-5500
2	Director U.S. Army Missile and Space Intelligence Center ATTN: AIMS-YRS (Thomas Blalock) (Pete Kirkland) Redstone Arsenal, AL 35898-5500

No. of Copies	Organization
2	Director U.S. Army Missile and Space Intelligence Center ATTN: AIMS-YRT (Francis G. Cline) (Don A. Slaymaker) Redstone Arsenal, AL 35898-5500
1	Director U.S. Army Missile and Space Intelligence Center ATTN: Randy L. Smith Redstone Arsenal, AL 35898-5500
1	Commander U.S. Army Tank-Automotive Command ATTN: AMCPM-BLK-III (COL Don Derrah) Warren, MI 48397-5000
1	Commander U.S. Army Tank-Automotive Command ATTN: AMSTA-CK (M. Erickson) Warren, MI 48090-5000
1	Commander U.S. Army Tank-Automotive Command ATTN: AMSTA-CK (Newell) Warren, MI 48090-5000
1	Commander U.S. Army Tank-Automotive Command ATTN: AMSTA-CR (Mr. Wheelock) Warren, MI 48397-5000
1	Commander U.S.. Army Tank-Automotive Command ATTN: AMSTA-CV (COL Becking) Warren, MI 48397-5000
2	Commander U.S. Army Tank-Automotive Command ATTN: AMSTA-NKS (D. Cyaye) (J. Rowe) Warren, MI 48397-5000
2	Commander U.S. Army Tank-Automotive Command ATTN: AMSTA-RG (R. Munt) (R. McClelland) Warren, MI 48397-5000

No. of Copies	Organization
2	Commander U.S. Army Tank-Automotive Command ATTN: AMSTA-RSC (John Bennett) (Wally Mick) Warren, MI 48397-5000
1	Commander U.S. Army Tank-Automotive Command ATTN: AMSTA-RSK (Sam Goodman) Warren, MI 48090-5000
1	Commander U.S. Army Tank-Automotive Command ATTN: AMSTA-RY (Ron Beck) Warren, MI 48397-5000
6	Commander U.S. Army Tank-Automotive Command ATTN: AMSTA-ZE (R. Asoklis) AMSTA-ZEA (C. Robinson) (R. Gonzalez) AMSTA-ZS (D. Rees) AMSTA-ZSS (J. Thompson) (J. Soltez) Warren, MI 48397-5000
1	Office of the PEO, Armored Sys Mod ATTN: SFAE-ASM-CV (Brian Bonkosky) Warren, MI 48397-5000
1	Commander HQ, TRADOC ATTN: Asst Dep Chief of Staff for Combat Operations Fort Monroe, VA 23651-5000
1	Commander TRADOC ATTN: ATAN-AP (Mark W. Murray) Ft. Monroe, VA 23651-5143
1	Director U.S. Army Engineer Waterways Experiment Station ATTN: CEWES-SE (Mr. Charles Joachim) 3909 Halls Ferry Road Vicksburg, MS 39180-6199

No. of Copies	Organization
1	Director U.S. Army Cold Regions Research and Development Laboratory ATTN: Technical Director (Lewis Link) 72 Lyme Road Hanover, NH 03755
1	U.S. Army Corps of Engineers Assistant Director Research and Development Directorate ATTN: Mr. B. Benn 20 Massachusetts Avenue, NW Washington, DC 20314-1000
1	Commander U.S. Army Operational Test and Evaluation Agency ATTN: MG Stephenson 4501 Ford Avenue Alexandria, VA 22302-1458
1	Commander U.S. Army Vulnerability Assessment Laboratory ATTN: SLCVA-CF (Gil Apodaca) White Sands Missile Range, NM 88002-5513
1	Director TRAC-WSMR ATTN: ATRC-RD (McCoy) WSMR, NM 88002-5502
2	U.S. General Accounting Office Program Evaluation and Methodology Division ATTN: Robert G. Orwin Joseph Sonnefeld Room 5844 441 G Street, NW Washington, DC 20548
1	Director U.S. Army Model Improvement and Study Management Agency ATTN: SFUS-MIS (Eugene P. Visco) 1900 Half Street, SW, Rm L101 Washington, DC 20324

No. of Copies	Organization
1	Director U.S. Army Industrial Base Engineering Activity ATTN: AMXIB-MT Rock Island, IL 61299-7260
1	Director U.S. Army Industrial Base Engineering Activity ATTN: AMXIB-PS (Steve McGlone) Rock Island, IL 61299-7260
3	Director U.S. Army Engineer Waterways Experiment Station ATTN: WESEN (Dr. V. LaGarde) (Mr. W. Grabau) WESEN-C (Mr. David Meeker) PO Box 631 Vicksburg, MS 39180-0631
1	U.S. Army Engineer Topographic Laboratories ATTN: Technical Director (W. Boge) Fort Belvoir, VA 22060-5546
1	Commander U.S. Army Operational Test and Evaluation Agency ATTN: LTC Gordon Crupper 4501 Ford Ave. #870 Alexandria, VA 22302-1435
1	PM-AFAS ATTN: SFAE-ASM-AF-E (T. Kuriata) Picatinny Arsenal, NJ 07806-5000
1	Commander David Taylor Research Center Code 1702 (Mr. Robert Wunderlick) Bethesda, MD 20084-5000
1	Commander David Taylor Research Center Code 1740.2 (Mr. Fred J. Fisch) Bethesda, MD 20084-5000

No. of Copies	Organization
1	Commander David Taylor Research Center Code 1750 (Mr. William Conley) Bethesda, MD 20084-5000
1	Director Lawrence Livermore National Laboratory ATTN: Mark Wilkins (L-3321) PO Box 808 Livermore, CA 94551
3	Director Los Alamos National Laboratory ATTN: Dean C. Nelson, MS 985 Gary Tietgen, MS F600 Terrence Phillips, MS G787 PO Box 1663 Los Aiamos, NM 87545
1	Director Los Alamos National Laboratory ATTN: LTC Michael V. Ziehmn, MS F681 USMC PO Box 1668 Los Alamos, NM 87545
1	Director Los Alamos National Laboratory ATTN: Dr. Roy A. Lucht, MS J960 Group M-B Los Alamos, NM 87545
1	Director Sandia National Laboratories Department 913 ATTN: Ron Andreas Albuquerque, NM 87185-5800
1	Director Sandia National Laboratories Division 1611 ATTN: Tom James Albuquerque, NM 87185
1	Director Sandia National Laboratories Division 1623 ATTN: Larry Hostetler Albuquerque, NM 87185

No. of Copies	Organization
1	Director Sandia National Laboratories ATTN: Gary W. Richter PO Box 969 Livermore, CA 94550
1	Commander Naval Air Systems Command JTCG/AS Central Office ATTN: 5164J (LTC James B. Sebolka) Washington, DC 20361
1	Commander ADR Program Manager CODE AIR-41112I ATTN: Tom Furlough Naval Air Systems Command Washington, DC 20361-4110
1	Commander Naval Ocean Systems Center ATTN: Earle G. Schweizer Code 000 San Diego, CA 92151-5000
5	Commander Naval Surface Warfare Center ATTN: Gregory J. Budd James Ellis Barbara J. Harris Constance P. Rollins Tom Wasmund Code G13 Dahlgren, VA 22448-5000
1	Commander Naval Surface Warfare Center ATTN: Glen Hornbaker Code G102 Dahlgren, VA 22448-5000
1	Commander Naval Surface Warfare Center ATTN: George Williams Code J33 Dahlgren, VA 22448-5000

No. of Copies	Organization
1	Commander Naval Surface Warfare Center ATTN: Frank Fassnacht 10901 New Hampshire Ave. Code N15 Silver Spring, MD 20903-5000
1	Commander Naval Surface Warfare Center ATTN: Norma D. Holland Code R-14 Silver Spring, Md 20903-5000
1	Commander Naval Surface Warfare Center ATTN: Dr. F.E. Baker 10901 New Hampshire Ave. Silver Spring, MD 20903-5000
1	Commander Naval Surface Warfare Center ATTN: William Emberson Code H021 10901 New Hampshire Avenue Silver Spring, MD 20903-5000
1	Commander Naval Surface Warfare Center ATTN: M. John Timo 10509 Edgefield Drive Adelphi, MD 20783-1130
2	Commander U.S. Naval Weapons Center ATTN: Jay Butterworth Dr. Helen Wang Code 3951 Bldg 1400, Room B20 China Lake, CA 93555-6001
1	Commander U.S. Naval Weapons Center ATTN: David H. Hall (Code 3181) China Lake, CA 93555-6001
1	Commander U.S. Naval Weapons Center ATTN: Mark D. Alexander (Code 3894) China Lake, CA 93556-6001

No. of Copies	Organization
1	Commander U.S. Naval Weapons Center ATTN: Melvin H. Keith (Code 35101) China Lake, CA 93555-6001
1	Commander U.S. Naval Weapons Center ATTN: Tim Horton (Code 3386) China Lake, CA 93555-6001
1	Commander U.S. Naval Weapons Center ATTN: Robert Cox, Code 3517 China Lake, CA 93555-6001
1	Commander U.S. Naval Civil Eng Laboratories ATTN: John M. Ferritto (Code L53) Port Hueneme, CA 93043
1	Naval Postgraduate School ATTN: Professor Robert E. Ball Department of Aeronautics and Astronautics Monterey, CA 93943
1	Naval Postgraduate School ATTN: Dr. Michael J. Zyda Department of Computer Science Code 52 Monterey, CA 93943-5000
1	Naval Postgraduate School Department of National Security ATTN: Dr. Joseph Sternberg Code 73 Monterey CA 93943
1	Commander Naval Air Systems Command ATTN: Mr. Philip Weinberg Code AIR-516J Washington, DC 20361-5160
1	Commander Naval Sea Systems Command ATTN: William G. Boyce Code 56Y52 Washington, DC 20362

No. of Copies	Organization
1	Commander Naval Sea Systems Command ATTN: Granville W. Broome SEA 5011 2521 Jefferson Davis Hwy. Arlington, VA 22202
1	Commander Naval Sea Systems Command ATTN: Philip M. Covich SEA 55X Washington, DC 20362-5101
2	Commander Naval Sea Systems Command ATTN: CPT Charles Calvano USN Robert Keane, Jr. SEA 50 Washington, DC 20362-5101
1	Commander Naval Sea Systems Command ATTN: Oliver F. Braxton 2521 Jefferson Davis Hwy. Arlington, VA 22202
1	Commander Naval Sea Systems Command ATTN: Donald Ewing Code 503 2521 Jefferson Davis Hwy. Arlington, VA 22202
1	Commander Naval Sea Systems Command ATTN: Anthony F. Johnson SEA 05R2 Washington, DC 20362-5101
1	Commander Naval Sea Systems Command ATTN: CPT William E. Mahew USN PMS 423 Washington, DC 20362-5101

No. of Copies	Organization
1	Commander Naval Sea Systems Command ATTN: Carl H. Pohler Code 05R23 Washington, DC 20362-5101
1	Commander Naval Sea Systems Command ATTN: Ronald P. Kramer SEA 50143 2521 Jefferson Davis Hwy. Arlington, VA 22202
1	Commander Naval Sea Systems Command ATTN: CPT R. Percival USN SEA 05T 2521 Jefferson Davis Hwy. Arlington, VA 22202
1	Commander Space and Naval Warfare Systems Command ATTN: Paul Wessel Code 30T Washington, DC 20363-5100
2	Commander David W. Taylor Naval Ship and Development Center ATTN: W. Conley J. Schot Bethesda, MD 20084
1	Office of Naval Technology ATTN: David J. Siegel 800 N. Quincy Street Arlington, VA 22217-5000
1	Commander Eglin Air Force Base 46 TW/EAL ATTN: Robert L. Stovall Eglin AFB, FL 32542-5000
1	Commander USAF HQ ESD/PLEA Chief, Engineering and Test Division ATTN: Paul T. Courtoglous Hanscom AFB, MA 01730

No. of Copies	Organization
2	Commander AFATL ATTN: AGA (Lawrence Jones) (Mickie Phipps) Eglin AFB, FL 32542-5434
1	WL/MNMW (Mr. John A. Collins) Eglin AFB, FL 32542
1	Commander AFEWC ATTN: AFEWC/SAXE (Bod Eddy) Kelly AFB, TX 78243-5000
1	Commander AFWAL/AARA ATTN: Ed Zelano Wright-Patterson AFB, OH 45433
1	Commander AFWAL/FIES ATTN: James Hodges Sr. Wright-Patterson AFB, OH 45433-6523
2	Commander AFWAL/MLTC ATTN: LT Robert Carringer Dave Judson Wright-Patterson AFB, OH 45433-6533
1	Commander ASB/XRM ATTN: Gerald Bennett Martin Lentz Wright-Patterson AFB, OH 45433
1	Commander WRDC/AARA ATTN: Michael L. Bryant Wright-Patterson AFB, OH 45433
1	Commander FTD/SDMBA ATTN: Charles Darnell Wright-Patterson AFB, OH 45433

No. of Copies	Organization
1	Commander FTD/SDMBU ATTN: Kevin Nelson Wright-Patterson AFB, OH 45433
1	Commander FTD/SQDRA ATTN: Greg Koesters Wright-Patterson AFB, OH 45433-6508
1	Commander FTD ATTN: Tom Reinhardt Wright-Patterson AFB, OH 45433
1	Commander FTD/SDAEA ATTN: Joe Sugrue Wright-Patterson AFB, OH 45433
1	Commander AFWAL/AARA ATTN: Vincent Velten Wright-Patterson AFB, OH 45433
1	Commander FTD/SQDRA ATTN: Larry E. Wright Wright-Patterson AFB, OH 45433
1	Commander AD/CZL ATTN: James M. Heard Eglin AFB, FL 32542-5000
1	Commander AD/ENYW ATTN: Jim Richardson Eglin AFB, FL 32542-5000
1	Commander Air Force Armament Laboratory ATTN: AFATL/DLY (James B. Flint) Eglin AFB, FL 32542-5000

No. of Copies	Organization
1	Commander U.S. Army FSTC/CA3 ATTN: Scott Mingledorff 220 Seventh Avenue Charlottesville, VA 22901-5396
1	Commander U.S. Army FSTC (UK) ATTN: MAJ J. Garnett 220 Seventh Avenue Charlottesville, VA 22901-5396
1	Commander U.S. Army FSTC ATTN: Dr. Tim Small 220 Seventh Avenue Charlottsville, VA 22901-5396
1	Defense Intelligence Agency ATTN: DB-6E3 (Jay Hagler) Washington, DC 20340-6763
5	Institute for Defense Analyses (IDA) ATTN: Mr. Irwin A. Kaufman Mr. Arthur O. Kresse Dr. Lowell Tonnessen Mr. Benjamin W. Turner Ms. Sylvia L. Waller Mr. Dave Hardison 1801 N. Beauregard Street Alexandria, VA 22311
1	Institute for Defense Analyses ATTN: Carl F. Kossack 1005 Athens Way Sun City, FL 33570
1	Institute for Defense Analyses ATTN: Dr. Natarajan Subramonian 14309 Hollyhock Way Burtonsville, MD 20866
1	Department of Commerce National Institute of Standards and Technology Manufacturing Systems Group ATTN: B. Smith Washington, DC 20234

No. of Copies	Organization
1	AAI Corporation ATTN: H. W. Schuette PO Box 126 Hunt Valley, MD 21030-0126
2	ADPA ATTN: Donna R. Alexander Bill King Two Colonial Place, Suite 400 2191 Wilson Boulevard Arlington, VA 22201-3061
1	Alliant Techsystems, Inc. ATTN: Paul Schmidt 7225 Northland Drive Brooklyn Park, NM 55428
1	ARC Professional Services Group ATTN: Arnold R. Gritzke 5501 Backlick Road Springfield, VA 22151
2	Advanced Marine Enterprises ATTN: James F. Hess CPT Frederic S. Hering USN (Ret) 1725 Jefferson Davis Highway Suite 1300 Arlington, VA 22202
2	Aero Corporation ATTN: David S. Eccles Gregg Snyder P.O. Box 92957, M4/913 Los Angeles, CA 90009
1	AFELM, The Rand Corporation ATTN: Library-D 1700 Main Street Santa Monica, CA 90406
2	Air Force Wright Aeronautical Labs ATTN: CDJ, CPT Jost CDJ, Joseph Faison Wright-Patterson AFB, OH 45433-6523

No. of Copies	Organization
1	Alliant Techsystems, Inc. ATTN: Hatem Nasr Systems and Research Center 3660 Technology Drive P.O. Box 1361 Minneapolis, MN 55418
2	Alliant Techsystems, Inc. ATTN: Raymond H. Burg Laura C. Dillway MN38-4000 10400 Yellow Circle Drive Minnetonka, MN 55343
1	Allison Gas Turbine Division of GM ATTN: William D. Farrar PO Box 420, SC S22B Indianapolis, IN 46260-0420
1	Aluminum Company of America ATTN: Frank W. Baker Alcoa Technical Center Alcoa Center, PA 15069
1	Analysis and Technology ATTN: RADM Thomas M. Hopkins USN (Ret) 1113 Carper Street McLean, VA 22101
1	ANSER ATTN: James W. McNulty 1215 Jefferson Davis Highway Arlington, VA 22202
1	ARC C-500 ATTN: John H. Bucher Modena Road Coatesville, PA 19320
1	Armored Vehicle Technologies ATTN: Coda M. Edwards PO Box 2057 Warren, MI 48090

No. of Copies	Organization
1	ASI Sytems, International ATTN: Dr. Michael Stamatelatos 3319 Lone Jack Road Encinitas, CA 92024
1	Auburn University Electrical Engineering Department ATTN: Dr. Thomas Shumpert Auburn University, AL 36849
1	A.W. Bayer and Associates ATTN: Albert W. Bayer, President Marina City Club 4333 Admiralty Way Marina del Rey, CA 90292-5469
1	Battelle ATTN: TACTEC Library (J.N. Huggins) 505 King Avenue Columbus, OH 43201-2693
1	Battelle Defense and Space Systems Analysis ATTN: Dr. Richard K. Thatcher 505 King Avenue Columbus, OH 43201-2693
1	Battelle ATTN: Bernard J. Tullington 4001 Fairfax Drive #600 Arlington, VA 22203-1617
3	Battelle Edgewood Operations ATTN: Roy Golly Gene Roecker Robert Jameson 2113 Emmorton Park Road Edgewood, MD 21040
1	The BDM Corporation ATTN: Edwin J. Dorchak 7915 Jones Branch Drive McLean, VA 22102-3396
1	The BDM Corporation ATTN: Fred J. Michel 4001 Fairfax Drive #750 Arlington, VA 22203-1618

No. of Copies	Organization
1	Bell Helicopter, Textron ATTN: Jack R. Johnson PO Box 482 Fort Worth, TX 76101
3	BMY, Division of Harsco ATTN: William J. Wagner, Jr. Ronald W. Jenkins Ed Magalski PO Box 1512 York, PA 17404
1	Board on Army Science and Technology National Research Council Room MH 280 2101 Constitution Avenue, NW Washington, DC 20418
2	Boeing Aerospace ATTN: Dr. Robert Chiavetta Dr. John Kuras Mail Stop 8K17 P.O. Box 3999 Seattle, WA 98124-2499
1	Boeing Military Airplanes ATTN: MS K80-08, Jerry White PO Box 7730 Wichita, KA 67277-7730
1	Boeing Vertol Company A Division of Boeing Co. ATTN: MS P30-27, John E. Lyons PO Box 16858 Philadelphia, PA 19142
1	Booz-Allen and Hamilton, Inc. ATTN: Dr. Richard B. Benjamin Suite 131, 4141 Colonel Glenn Hwy. Dayton, OH 45431
2	Booz-Allen and Hamilton, Inc. ATTN: John M. Vice WRDC/FIVS/SURVIAC Bldg 45, Area B Wright-Patterson AFB, OH 45433-6553

No. of Copies	Organization
1	John Brown Associates ATTN: Dr. John A. Brown PO Box 145 Berkeley Heights, NJ 07922-0145
1	Chamberlain ATTN: Mark A. Sackett PO Box 2545 Waterloo, IA 50704
1	Commander Combined Arms Combat Development ATTN: ATZL-CAP (LTC Morrison Dir, Surv Task Force) Ft. Leavenworth, KS 66027-5300
1	Commander Combined Arms Combat Development ATTN: ATZL-HFM (Dwain Skelton) Ft. Leavenworth, KS 66027-5300
1	Computer Sciences Corporation ATTN: Abner W. Lee 200 Sparkman Drive Huntsville, AL 35805
1	CRS Sirrine, Inc. ATTN: Dr. James C. Smith PO Box 22427 1177 West Loop South Houston, TX 77227
2	Cypress International ATTN: August J. Caponecchi James Logan 1201 E. Abingdon Drive Alexandria, VA 22314
1	DATA Networks, Inc. ATTN: William E. Regan, Jr. President 288 Greenspring Station Brooklandville, MD 21022
1	Datatec, Inc. ATTN: Donald E. Cudney President 326 Green Acres Fort Walton, FL 32548

No. of Copies	Organization
1	David Taylor Research Center ATTN: Robert E. Fuss UERD, Code 177 Portsmouth, VA 23709-5000
1	David Taylor Research Center ATTN: Seymour N. Goldstein Code 1210 Bethesda, MD 20084-5000
1	David Taylor Research Center ATTN: Ib S. Hansen Code 174 Bethesda, MD 20084-5000
1	David Taylor Research Center ATTN: Harry Price Gray Code 1740.4 Bethesda, MD 20084-5000
1	David Taylor Research Center ATTN: Jackson T. Hawkins Code 1740.2 Bethesda, MD 20084-5000
1	David Taylor Research Center ATTN: Steven L. Cohen Code 1230 Bethesda, MD 20084-5000
1	David Taylor Research Center ATTN: Dennis Clark Code 0111 Bethesda, MD 20084-5000
1	David Taylor Research Center ATTN: John R. Krezel UERD, Code 177.2 Portsmouth, VA 23709-5000
1	David Taylor Research Center ATTN: Richard E. Metrey Code 01 Bethesda, MD 20084-5000
1	David Taylor Research Center ATTN: Dr. Paul C. St. Hilaire Code 1210 Bethesda, MD 20084-5000

No. of Copies	Organization
1	David Taylor Research Center ATTN: Arthur Marchand Code 2843 Annapolis, MD 21042
1	David Taylor Research Center ATTN: Michael Riley UERD, Code 177 Portsmouth, VA 23709-5000
1	David Taylor Research Center ATTN: J. William Sykes Code 175 Bethesda, MD 20084-5000
1	David Taylor Research Center ATTN: Herbert Wolk Code 1740.1 Bethesda, MD 20084-5000
1	University of Dayton Graduate Engineering and Research *Kettering Lab 262* ATTN: Dr. Gary Thiele, Director Dayton, OH 45469
1	Defense Nuclear Agency Structural Dynamics Section ATTN: Tom Tsai Washington, DC 20305
1	Delco Systems Operation ATTN: John Steen 6767 Hollister Avenue, #P202 Goleta, CA 93117
2	Denver Research Institute BW 228 ATTN: Lawrence G. Ullyatt ATTN: Larry Nutsch 2050 E. Iliff Avenue Denver, CO 80208
1	Dow Chemical, U.S.A ATTN: Dr. P. Richard Stoesser Contract R&D 1801 Building Midland, MI 48674-1801

No. of Copies	Organization
1	Drexel University ATTN: Dr. Pei Chi Chou College of Engineering Philadelphia, PA 19104
1	DuPont Company FPD ATTN: Dr. Oswald R. Bergmann B-1246, 1007 Market Street Wilmington, DE 19898
1	Dynamics Analysis and Test Associates ATTN: Dr. C. Thomas Savell 2231 Faraday Ave Suite 103 Carlsbad, CA 92008
1	E. I. Dupont TED FMC ATTN: Richard O. Myers Jr. Wilmington, DE 19898
1	Eichelberger Consulting Company ATTN: Dr. Robert Eichelberger President 409 West Catherine Street Bel Air, MD 21014
1	Electronic Warfare Associates, Inc. ATTN: William V. Chiaramonte 2071 Chain Bridge Road Vienna, VA 22180
1	Emprise, Ltd. ATTN: Bradshaw Armendt, Jr 201 Crafton Road Bel Air, MD 21014
8	Environmental Research Institute of Michigan ATTN: Mr. K. Augustyn Mr. Kozma Dr. I. La Haie Mr. R. Horvath Mr. Arnold Mr. E. Cobb Mr. B. Morey Mr. M. Bair PO Box 134001 Ann Arbor, MI 48113-4001

No. of Copies	Organization
1	E-OIR Measurements, Inc. ATTN: Russ Moulton PO Box 1240 Spotsylvania, VA 22553-1240
1	ERIM ATTN: Stephen R. Stewart Exploitation Applications Department Image Processing Systems Division PO Box 8618 Ann Arbor, MI 48107-8618
1	USA ETL/IAG ATTN: Jim Campbell Bldg 2592, Room S16 Ft. Belvoir, VA 22060-5546
1	FMC Corporation ATTN: Sidney Kraus 1105 Coleman Ave, Box 1201 San Jose, CA 95108
3	FMC Corporation ATTN: Ronald S. Beck Martin Lim Jacob F. Yacoub 881 Martin Avenue Santa Clara, CA 95052
1	BDM International ATTN: Mr. Steve Church, FX2B307 7915 Jones Branch Drive McLean, VA 22102-3396
1	BDM International ATTN: Mr. Tom Hooker, FF2B304 7915 Jones Branch Drive McLean, VA 22102-3396
1	Comarco Weapons Support Division ATTN: Robert Sewell 1201 N. China Lake Boulevard Ridgecrest, CA 93555

No. of Copies	Organization
2	FMC Corporation Defense Systems Group ATTN: Robert Burt Dennis R. Nitschke 1115 Coleman Avenue San Jose, CA 95037
1	FMC Corporation Naval Systems Division (NSD) ATTN: MK-45, Randall Ellis 4800 East River Road Minneapolis, MN 55421-1498
1	FMC Corporation Northern Ordnance Division ATTN: M3-11, Barry Brown 4800 East River Road Minneapolis, MN 55421-1498
6	FMC Corporation Ordnance Engineering Division ATTN: H. Croft M. Hatcher L. House J. Jackson E. Maddox R. Musante 1105 Coleman Ave, Box 1201 San Jose, CA 95108
1	GE Aircraft Engines ATTN: Dr. Roger B. Dunn One Neumann Way, MD J185 Cincinnati, OH 45215-6301
1	General Atomics ATTN: Chester J. Everline, Staff Engineer P.O. Box 85608 San Diego, CA 92138-5608
1	General Dynamics ATTN: Dr. Fred Cleveland P.O. Box 748 Mail Zone 5965 Ft. Worth, TX 76101

No. of Copies	Organization
1	General Dynamics Land Systems ATTN: MZ-4362055, Gary Jackman P.O. Box 2074 Warren, MI 48317
3	General Dynamics Corporation ATTN: MZ-2650, Dave Bergman MZ-2860, John Romanko MZ-2844, Cynthia Waters PO Box 748 Ft. Worth, TX 76101-0748
1	General Dynamics Land Systems ATTN: Dr. Paulus Kersten P.O. Box 2074 Warren, MI 48317
1	General Dynamics Land Systems ATTN: William M. Mrdeza PO Box 2074 Warren, MI 48317
5	General Dynamics Land Systems ATTN: Richard Auyer Otto Renius N. S. Sridharan Dean R. Loftin Dr. Phil Lettn PO Box 2074 Warren, MI 48090-2074
2	General Motors Corporation Research Laboratories ATTN: J. Boyse R. Sarraga Warren, MI 48090
1	Allison Gas Turbine Division General Motors Corporation ATTN: John A. MacBain, Ph.D., Supervisor Low Observables Technology P.C. Box 420, Speed Code W-16 Indianapolis, IN 46206-0420
1	Gettysburg College Box 405 Gettysburg, PA 17325

No. of Copies	Organization
1	GTRI-RAIL-MAD ATTN: Mr. Joe Bradley CRB 577 Atlanta, GA 30332
1	Hughes Associates ATTN: J. Thomas Hughes 6770 Oak Hall Ln #125 Columbia, MD 21045-4768
2	INEL/EG&G Engineer Lab ATTN: Ray Berry M. Marx Hintze PO Box 1625 Idaho Falls, ID 83451
1	Interactive Computer Graphics Center Rensselear Polytechnic Inst. ATTN: M. Wozny Troy, NY 12181
1	International Development Corporation ATTN: Trevor O. Jones, President One Cleveland Center, Suite 2900 1375 East Ninth Street Cleveland, OH 44114-1724
1	Intergraph National Exploitation Systems ATTN: John H. Suter 2051 Mercator Drive Reston, VA 22091-3413
1	ISAT ATTN: Roderick Briggs 1305 Duke Street Alexandria, VA 22314
1	ITT Defense ATTN: Joseph Conway 1000 Wilson Blvd. 30th Floor Arlington, VA 22209

No. of Copies	Organization
1	Joint Technical Coordinating Group ATTN: Philip Weinberg JTCG/AS5 AIR-516J5 Washington, DC 20361-5160
1	California Institute of Technology Jet Propulsion Laboratory ATTN: D. Lewis 4800 Oak Grove Drive Pasadena, CA 91109
1	Kaman Sciences Corporation ATTN: Timothy S. Pendergrass 600 Boulevard South, Suite 208 Huntsville, AL 35802
1	Ketron, Inc. ATTN: Robert S. Bennett 901 Dulaney Valley Rd, Suite 220 Baltimore, MD 21204-2600
1	Keweenaw Research Center Michigan Technological University ATTN: Bill Reynolds Houghton, MI 49931
1	Lanxido Armor Products ATTN: Dr. Robert A. Wolffe Tralee Industrial Park Newark, DE 19711
1	Meredith Company ATTN: Dr. F. Paul Carlson 5001 West 80th Street Suite 500 Minneapolis, MN 55437
2	Lincoln Laboratory MIT ATTN: Dr. Robert Shin Dr. Chuck Burt P.O. Box 73 Lexington, MA 02173

No. of Copies	Organization
3	Lincoln Laboratory MIT Surveillance Systems Group ATTN: R. Barnes G. Knittel J. Kong 244 Wood Street Lexington, MA 02173-0073
3	Lockheed-California Company ATTN: C. A. Burton R. J. Ricci M. Steinberg Burbank, CA 91520
1	Lockheed Palo Alto Research Lab ATTN: John A. DeRuntz, Jr. 0/93, B/25I 3251 Hanover Street Palo Alto, CA 94304
1	Logistics Management Institute ATTN: Edward D. Simms Jr. 6400 Goldsboro Road Bethesda, MD 20817-5886
1	Los Alamos Technical Associates, Inc. ATTN: Jon Davis 6501 Americas Parkway, #900 Albuquerque, NM 87110
2	Los Alamos Technical Associates, Inc. ATTN: James C. Jacobs Donald M. Lund 8550 Arlington Boulevard Suite 301 Fairfax, VA 22031
1	LTV Aerospace and Defense Company ATTN: Daniel M. Reedy PO Box 655907 Dallas, TX 75265-5907
3	Martin Marietta Aerospace ATTN: MP-113, Dan Dorfman MP-433, Richard S. Dowd MP-243, Thomas C. D'Isepo PO Box 555837 Orlando, FL 32855-5837

No. of Copies	Organization
1	Maxwell Laboratories, Inc. ATTN: Dr. Michael Holland 8888 Balboa Avenue San Diego, CA 92123-1506
1	McDonnell Douglas Astronautic ATTN: Nikolai A. Louie 5301 Bolsa Avenue Huntington Beach, CA 92647
1	McDonnell Douglas, Inc. ATTN: David Hamilton PO Box 516 St. Louis, MO 63166
1	McDonnell Douglas, Inc. ATTN: Alan R. Parker 3855 Lakewood Blvd., MC 35-18 Long Beach, CA 90846
1	Micro Electronics of North Carolina ATTN: Gershon Kedem PO Box 12889 Research Triangle Park, NC 07709
1	MIT ATTN: Dr. S. Benton RE15-416 Cambridge, MA 02139
6	The MITRE Corporation ATTN: Mr. Edward C. Brady, Vice President Dr. Robert Henderson Dr. Nicklas Gramenopoulos Dr. Narayana Srinivasan Mr. Norman W. Huddy Dr. John M. Ruddy 7525 Colshire Drive McLean, VA 22102-3184
2	NFK Engineering, Inc. ATTN: Dr. Michael P. Pakstys Justin W. Held 4200 Wilson Blvd. Arlington, VA 22203-1800

No. of Copies	Organization
1	NFK Engineering, Inc. ATTN: John J. Turner 1125 Trotting Horse Lane Great Falls, VA 22066
1	NASA-Ames Research Center ATTN: Dr. Alex Woo Mail Stop 227-2 Moffett Field, CA 94035-1000
1	NASA-Ames Research Center ATTN: Leroy Presley Mail Stop 227-4 Moffett Field, CA 94035-1000
1	NAVIR DEVCON ATTN: Frank Wenograd Code 6043 Walminstor, PA 18974
1	North Aircraft ATTN: Dr. Athanosis Varvatsis Mail Zone 3622/84 1 Northrop Ave Hawthorne, CA 90250
1	Northrop Research and Technology Center ATTN: Dr. David Donovan Garber One Research Park Palos Verdes Peninsula, CA 90274
1	Norton Company ATTN: Ronald K. Bart 1 New Bond Street Worcester, MA 01606-2698
1	The Oceanus Company ATTN: RADM Robert H. Gormley, (Ret) PO Box 7069 Menlo Park, CA 94026
1	Oklahoma State University College of Engineering, Architecture and Technology ATTN: Thomas M. Browder, Jr. PO Box 1925 Eglin AFB, FL 32542

No. of Copies	Organization
1	Pacific Scientific/Htl Division ATTN: Robert F. Aldrich 1800 Highland Avenue Duarte, CA 91010
1	Princeton University Mathematics Department Fine Hall Washington Road ATTN: John Tukey Princeton, NJ 08544-1000
1	PRI, Inc. ATTN: W. Bushell Building E4435, Second Floor Edgewood Area-APG, MD 21010
1	Rockwell International Corporation ATTN: Dr. H. Bran Tran P.O. Box 92098 Department 113/GB01 Los Angeles, CA 90009
1	Rome Air Development Center ATTN: RADC/IRRE, Peter J. Costianes Griffis Air Force Base, NY 13441-5700
1	Rome Air Development Center RADC/OCTM ATTN: Edward Starczewski Building 106 Griffis Air Force Base, NY 13441-5700
1	S-Cubed ATTN: Michael S. Lancaster 1800 Diagonal Road, Suite 420 Alexandria, VA 22314
1	Sachs/Freeman Associates, Inc. ATTN: Donald W. Lynch Senior Research Physicist 205 Yoakum Parkway, #511 Alexandria, VA 22304
1	SAIC ATTN: Dr. Alan J. Toepfer 2109 Air Park Drive, SE Albuquerque, NM 87106

No. of Copies	Organization
1	SAIC ATTN: John H. McNeilly, Senior Scientist 1710 Goodridge Drive McLean, VA 22102
2	SAIC ATTN: Terry Keller Robert Turner Suite 200 1010 Woodman Drive Dayton, OH 45432
1	SAIC ATTN: David R. Garfinkle Malibu Canyon Business Park 26679 W. Agoura Road, Suite 200 Calabasas, CA 91302
2	George Sharp Company ATTN: Dennis M. McCarley Roger O. Mau 2121 Crystal Drive Suite 714 Arlington, VA 22202
1	Sidwell-Ross and Associates, Inc. ATTN: LTG Marion C. Ross, (USA Ret) Executive Vice President PO Box 88531 Atlanta, GA 30338
1	Sigma Research Inc. ATTN: Dr. Richard Bossi 4014 Hampton Way Kent, WA 98032
1	Simula, Inc. ATTN: Joseph W. Coltman 10016 South 51st Street Pheonix, AZ 85044
1	SimTech ATTN: Dr. Annie V. Saylor 3307 Bob Wallace Ave., Suite 4 Huntsville, AL 35807

No. of Copies	Organization
1	Alan Smolen and Associates, Inc. ATTN: Alan Smolen, President One Cynthia Court Palm Coast, FL 32027-8172
3	Southwest Research Institute ATTN: Martin Goland Alex B. Wenzel Patrick H. Zabel P.O. Drawer 28255 San Antonio, TX 78228-0255
3	Sparta, Inc. ATTN: David M. McKinley Robert E. O'Connor Karen M. Rooney 4901 Corporate Drive Huntsville, AL 35805-6201
1	SRI International ATTN: Donald R. Curran 333 Ravenswood Ave. Menlo Park, CA 94025
1	Star Laboratory, Stanford University ATTN: Dr. Joseph W. Goodman Electrical Engineering Department 233 Durand Building Stanford, CA 94305-4055
1	University of Michigan ATTN: Dr. John F. Vesecky 2212 Space Research Blvd. Ann Arbor, MI 48109-2143
1	Princeton University ATTN: Dr. Curt Callen Physics Department PO Box 708 Princeton, NJ 08544
1	University of California, San Diego ATTN: Dr. Gordon J. MacDonald Institute on Global Conflict and Cooperation (0518) 9500 Gilman Drive La Jolla, CA 92093-0518

No. of Copies	Organization
1	Structural Dynamics Research Corporation (SDRC) ATTN: R. Ard 2000 Eastman Drive Milford, OH 45150
1	Syracuse Research Group ATTN: Dr. Chung-Chi Cha Merrill Lane Syracuse, NY 13210
1	System Planning Corporation ATTN: Ann Hafer 1500 Wilson Blvd Arlington, VA 22209
1	S-Cubed ATTN: Robert T. Sedgwick PO Box 1620 La Jolla, CA 92038-1620
2	TASC ATTN: Richard E. Kinsler Darrell James 1992 Lewis Turner Boulevard Ft. Walton Beach, FL 32548-1255
1	TASC ATTN: COL James Logan (Ret) 1101 Wilson Blvd. Suite 1500 Arlington, VA 22209
1	COLSA, Inc. ATTN: Mr. Willy Albanes P.O. Box 1068 Huntsville, AL 35807-3301
1	Techmatics, Inc. ATTN: Ronald R. Rickwald 2231 Crystal Drive Arlington, VA 22202-3742
1	Technical Solutions, Inc ATTN: John R. Robbins P.O. Box 1148 Mesillia Park, NM 88047

No. of Copies	Organization
1	Teledyne Brown Engineering ATTN: John W. Wolfsberger, Jr. Cummings Research Park 300 Sparkman Drive, NW PO Box 070007 Huntsville, AL 35807-7007
1	Tradeways, Ltd. ATTN: Joseph G. Gorski, President 307F Maple Avenue West Vienna, VA 22180
1	Ultramet ATTN: Dr. Jacob J. Stiglich 12173 Montague Street Pacoima, CA 91331
1	United Technologies Corporation Advanced Systems Division ATTN: Richard J. Holman 10180 Telesis Court San Diego, CA 92121
1	VP Consultants, Inc. ATTN: Mr. Albert E. Papazoni 1600 Surrey Hill Drive Austin, TX 78746-7338
1	University of Idaho Department of Civil Engineering ATTN: Dr. Dennis R. Horn Assistant Professor Moscow, ID 83843-4194
1	University of Illinois at Chicago Communications Laboratory ATTN: Dr. Wolfgang-M. Boerner PO Box 4348 M/C 154, 1141-SEO Chicago, IL 60680
1	University of Illinois at Urbana-Champaign Department of Civil Engineering and Environmental Studies ATTN: Dr. E. Downey Brill, Jr. 208 North Romine Urbana, IL 61801-2374

No. of Copies	Organization
1	University of Illinois at Urbana-Champaign Department of Electrical and Computer Engineering ATTN: Dr. Shung-Wu Lee 1406 W. Green Urbana, IL 61801
1	The Johns Hopkins University Applied Physics Laboratory ATTN: Jonathan Fluss Johns Hopkins Road Laurel, MD 20707
1	University of Nevada Environmental Research Center ATTN: Dr. Delbert S. Barth Senior Scientist Las Vegas, NV 89154-0001
1	University of North Carolina ATTN: Professor Henry Fuchs 208 New West Hall (035A) Chapel Hill, NC 27514
3	Ohio State University Electroscience Laboratory ATTN: Dr. Ronald Marhefka Dr. Edward H. Newman Dr. Prasbhaker H. Pathak 1320 Kinnear Road Columbus, OH 43212
1	University of Rochester ATTN: Nicholas George College of Engineering and Applied Science Rochester, NY 14627
3	University of Utah Computer Science Department ATTN: R. Riesenfeld E. Cohen L. Knapp 3160 Merrill Engineering Bldg Salt Lake City, UT 84112

No. of Copies	Organization
3	University of Washington 409 Department of Electrical Engineering, FT-10 ATTN: Dr. Irene Peden Dr. Akira Ishimaru Dr. Chi Ho Chan Seattle, WA 98105
1	Virginia Polytechnic Institute and State University Industrial Engineering Operations Research Department ATTN: Robert C. Williges 302 Whittemore Hall Blacksburg, VA 24061-8603
1	LTV Aircraft Products Group ATTN: Paul T. Chan, M/S 194-63 PO Box 655907 Dallas, TX 75265-5907
1	LTV Aerospace and Defense Company LTV Missiles and Electronics Group ATTN: Roger W. Melin PO Box 650003 M/S EM-36 Dallas, TX 75265-0003
1	Wackenhut Applied Technologies Center ATTN: Robert D. Carpenter David L. Rigotti 10530 Rosehaven St. Suite 500 Fairfax, VA 22030-2877
1	Westinghouse ATTN: Harvey Kloehn Box 1693 MS 8530 Baltimore, MD 21203
1	XMCO, Inc. 460 Spring Park Pl #1500 Herndon, VA 22070-5215
1	Zernow Tech Services, Inc. ATTN: Dr. Louis Zernow 425 West Bonita, Suite 208 San Dimas, CA 91773

No. of Copies	Organization
4	SURVICE Engineering ATTN: Jim Foulk George Large Glenn Gillis Kris Keller Suite 103 1003 Old Philadelphia Road Aberdeen, MD 21001
2	Sverdrup Technology ATTN: Dr. Ralph Calhoun Bud Bruenning PO Box 1935 Eglin AFB, FL 32542
1	Georgia Technical Research Institute Systems and Technical Laboratory ATTN: Dr. Charles Watt 1770 Richardsons Road Smyrna, GA 30080
1	Georgia Institute of Technology ATTN: Dr. Richard Moore ECSL/EME ERB Building, Room 111 Atlanta, GA 30332
1	Georgia Institute of Technology ATTN: Dr. L. G. Callahan, Jr. School of Industrial & Systems Engineering 765 Ferst Drive Atlanta, GA 30332-0385
1	Duke University Department of Computer Science, VLSI Raycasting ATTN: Dr. Gershon Kedem 236 North Building Durham, NC 27706
1	Paladin Software P.O. Box 187 Aberdeen, MD 21001
1	UNISYS Corporation ATTN: Calvin M. Shintani 12010 Sunrise Valley Drive Department 7412 Reston, VA 22091

No. of Copies	Organization
1	Weidlinger Assoicates, Inc. ATTN: Kenneth Stultz 1735 Jefferson Davis Hwy. Suite 1002 Arlington, VA 22202
1	Mr. Charles W. Bernard 5300 Columbia Pike Apt #902 Arlington, VA 22204
1	Mr. Michael W. Bernhardt, DA Consultant Rt. 1, 12 Arthur Drive Hockessin, DE 19707
1	Perkins Coie ATTN: Mr. Robert L. Deitz 607 Fourteenth Street, NW Washington, DC 20005-2011
1	Mr. Gerard W. Elverum, Jr. 1338 Fair Oaks Avenue Banning, CA 92220
1	National Research Council ATTN: Mr. Richard E. Entlich 2101 Constitution Ave., NW Harris Building #254 Washington, DC 20418
1	Napadensky Energetics, Inc. ATTN: Mrs. Hyla Napadensky 650 Judson Avenue Evanston, IL 60202-2551
1	University of Iowa College of Engineering Center for Computer Aided Design ATTN: Dr. Edward J. Haug Iowa City, IA 52242
1	Hodges Transportaiton, Inc. ATTN: Mr. Harvey E. Cale P.O. Box 234 Carson City, NV 89702

No. of Copies	Organization
1	Orincon Corporation ATTN: Mr. Robert M. Hillyer 9363 Towne Centre Drive San Diego, CA 92121
1	Dr. Robert B. LaBerge 910 Via Palo Aptos, CA 95003
1	Orr Associates, Inc. ATTN: Dr. Joel N. Orr 5224 Indian River Road Virginia Beach, VA 23464
1	Mr. Abraham Golub DA Consultant 203 Yoakum Parkway, Apt 607 Alexandria, VA 22304
1	Mr. Dave Hardison ASB Consultant 3807 Bent Branch Road Falls Church, VA 22041
1	Mr. William M. Hubbard, ASB Consultant 613 Eastlake Drive Columbia, MO 65203
1	Dr. Edward R. Jones, DA Consultant 9881 Wild Deer Road St. Louis, MO 63124
1	MG Robert Kirwan (USA Ret), DA Consultant 10213 Grovewood Way Fairfax, VA 22032
1	Director TEXCOM FSTP ATTN: STE-TFS-Z (Donald J. Krejcarek) Ft. Sill, OK 73503-6100
1	Mr. Robert B. Kurtz DA Consultant 542 Merwins Lane Fairfield, CT 06430-1920

No. of Copies	Organization
1	LTGEN Howard W. Leaf USAF (Retired) Director, Test and Evaluation HQ, USAF/TE Pentagon, Rm 4E995 Washington, DC 20330
1	Cincinnati Mailacron Inc. ATTN: Mr. Richard C. Messinger Vice President and Chief Technical Officer Cincinnati, OH 45209
1	Coleman Research Corporation ATTN: GEN Glenn Otis USA (Ret) 5950 Lakehurst Drive Orlando, FL 32819
1	MG Peter G. Olenchuk (USA Ret), BAST Consultant 6801 Baron Road McLean, VA 22101
1	Harry Reed, Sr. Battelle Consultant 138 Edmund Street Aberdeen, MD 21001
1	Mr. David L. Rigotti McClean Research Consultant 127 Duncannon Road Bel Air, MD 21014
1	Dr. A. E. Schmidlin, DA Consultant 28 Highview Road Caldwell, NJ 07006-5502
1	Mr. Robert G.S. Sewell 1236 Mt. Whitney Lane Ridgecrest, CA 93555
1	MEMEX Corporation ATTN: Mr. Charles S. Smith 9 Doaks Lane Marblehead, MA 01945

No. of Copies	Organization
1	Mr. Arthur Stein, Consultant Institute for Defense Analyses 30 Chapel Woods Court Williamsville, NY 14221-1816
1	Dr. Dora Strother, ASB Consultant 3616 Landy Lane Ft. Worth, TX 76118
1	Mr. Charles F. Tiffany 9 Westerly Lane Centerville, OH 45458

Aberdeen Proving Ground

18	Dir, USAMSAA ATTN: AMXSY-A, W. Clifford J. Meredith AMXSY-C, A. Reid W. Braerman AMXSY-CR, M. Miller AMXSY-CS, P. Beavers C. Cairns D. Frederick AMXSY-G, W. Brooks G. Comstock E. Christman L. Kravitz AMXSY-GA, W. Brooks AMXSY-J, A. LaGrange AMXSY-L, J. McCarthy AMXSY-P, J. Cullum AMXSY-RA, R. Scungio M. Smith
5	Cdr, USATECOM ATTN: AMSTE-CG AMSTE-TA-L, A. Yankolonis N. Harrington S. Grill AMSTE-TC-C, R. Cozby